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AQUATIC TOXICITY AND BIOACCUMULATION POTENTIAL OF PCBs IN THE MARINE ENVIRONMENT

-- Implications for the Acushnet River Estuary --

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This document is a review of scientific literature pertaining to the effects of PCBs on marine organisms. It is beyond the scope of the document, with few exceptions, to critique the studies that are reviewed. Review of the studies should not be construed as an indication of agreement with the experimental design or results of the studies.

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1. TOXICITY OF PCBs TO MARINE ORGANISMS

Investigations of toxicity of PCBs to marine organisms have primarily focused upon the toxicity of commercial Aroclor (Monsanto) formulations. Aroclor 1254 has been the most commonly investigated formulation, but attention also has been directed to Aroclors 1016, 1242, and 1268.

Aroclor 1016 contains approximately 40% chlorine by weight and has a solubility in seawater of about 906 ppb (ERCO, 1982). This Aroclor formulation contains mono-, di-, tri-, and tetrachlorobiphenyl isomers, although it is dominated by biphenyl molecules bonded to 3 chlorine atoms (Hutzinger et al., 1974).

Aroclor 1242, which is similar to Aroclor 1016 in terms of physical and chemical characteristics, contains approximately 42% chlorine by weight and has a solubility in water of about 240 ppb (Kimbrough, 1980). It contains mono-, di-, tri-, tetra-, penta-, and hexachlorobiphenyl isomers (Hutzinger et al., 1974), with domination by 3-chlorine and, to a lesser extent, 4-chlorine congeners (Brinkman and DeKok , 1980).

Aroclor 1254 contains approximately 54% chlorine by weight and has a solubility in water of about 12 ppb (Kimbrough, 1980). It contains tri-, tetra-, penta-, hexa-, and heptachlorobiphenyl isomers, with domination by (in decreasing order of abundance) 5-chlorine, 6-chlorine, and 4-chlorine congeners (Hutzinger et al., 1974).

Aroclor 1268 is similar in physical and chemical attributes to Aroclor 1260, which, although not extensively investigated for its toxicity to marine organisms, has been studied for its potential to bioaccumulate in the marine environment. Aroclor 1260 contains approximately 60% chlorine by weight and has a solubility in water of about 3 ppb (Kimbrough, 1980). It contains penta-, hexa-, hepta-, octa-, and nonachlorobiphenyl isomers (Hutzinger et al., 1974), with domination

(in decreasing order of abundance) by 6-chlorine, 7-chlorine, and 5-chlorine congeners (Chase et al., 1989).

Although Aroclors 1016, 1242, 1254, and 1260 are characterized by progressively greater chlorine content and progressively lesser solubility in water, each of the formulations "overlaps" with the others in terms of some congeners. This overlap is least in the case of Aroclors 1016 and 1242 versus Aroclor 1260. In general, the average congener in the formulations contains the following number of chlorine atoms -- Aroclors 1016 and 1242: 3 chlorines; Aroclor 1254: 5 chlorines; and Aroclor 1260: 6 chlorines.

Logic suggests a positive correlation between level of chlorination in an Aroclor and its potential toxicity to marine organisms. Actual toxicity to organisms may be a different matter if the lesser water solubility of the highly chlorinated Aroclors limits their availability to organisms. Toxicity of Aroclors to marine organisms may also be a function of the planarity (i.e., "flatness') of Aroclor molecules, which is influenced by the location of chlorine atoms on the biphenyl rings. For example, toxicological investigations with mammals have indicated (Safe, 1984) that the most biologically active congeners of PCBs are tetra-, penta-, and hexachlorobiphenyls; and that the most toxic of these congeners (3,3′, 4, 4′-tetra-, 3,3′, 4, 4′, 5-penta-, and 3,3′, 4, 4′, 5, 5′-hexachlorobiphenyls) are substituted at both "para" and at two or more "beta" positions on the biphenyl rings. It is important to note that the above-identified toxic isomers are either absent or present in only small amounts in Aroclors 1016, 1242, 1254, and 1260 (Chase et al., 1989).

1.1 Experimental Studies with PCBs

Toxicological studies have been performed in which marine organisms were exposed in the laboratory (under controlled experimental conditions) to various commercial formulations of PCBs contained in water, sediment, and food. Unfortunately, the implication of a particular PCB-laden environmental medium with toxicological effects in marine organisms often provides little insight into the exact vectors or routes of the effects. This is particularly true in the case of sediment studies since toxicological responses of organisms could reflect direct contact with and/or ingestion of in situ sediment, suspended sediment particles,

and/or associated water. In addition, direct-contact and ingestion routes could entail both adsorption, and the potentially more serious absorption, of PCBs by organisms. To a lesser degree, water and food studies could be biased by transfer of PCBs from the environmental medium being investigated to associated media (particulate matter and food in the case of water studies; particulate matter and water in the case of food studies).

1.1.1 PCBs in Water

Toxicity of several water-borne commercial PCB formulations -- Aroclors 1016, 1242, 1254, and 1268 -- has been investigated with a variety of marine phytoplankton, zooplankton, benthos, and fishes (Table 1). The information presented in that table (and other tables contained in this document) constitutes only part of the voluminous data pertaining to PCBs, but is believed to be representative of those data. The inclusion of information in the table does not imply a judgement as to the quality of the toxicity tests that generated the information. However, the range in quality is substantial, as evidenced by tests in which toxicological responses by test organisms were reported to occur at PCB concentrations in water that were not measured, but simply inferred on the basis of a priori calculations.

Toxicological responses described in Table 1 consist of 96-hr median lethal concentrations (LC50s) of PCBs and maximum acceptable toxicant concentrations (MATCs) of PCBs for various biological variables (life functions). As in the case of LC50s, MATCs are exposure-time-specific toxicological statistics (refer to second column of table for appropriate exposure times) in that shorter and longer exposure periods would be expected to cause MATCs to respectively, increase and decrease. Life functions addressed in the table are usually of substantial environmental importance, i.e., they pertain to such vital biological functions as survival and growth. However, some life functions included in the table (e.g., rate of fin regeneration in gulf killifish and all phytoplankton measurements) have limited environmental significance.

Table 1. __ Toxicological responses of marine organisms exposed to polychlorinated biphenyls (PCBs) in water[a]

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1016		
Benthos				
1. Crassostrea virginica (American oyster)	96 hr	Survival	96 - hr LC50 = 10.2	Hansen et al., 1974a
2. Penaeus aztecus (brown shrimp)	96 hr	Survival	96 - hr LC50 = 10.5	Hansen et al., 1974a
3. Palaemonetes pugio (grass shrimp)	96 hr	Survival	96 - hr LC50 = 12.5	Hansen et al., 1974a
Fishes				
1. Lagodon rhomboides (pinfish)	96 hr	Survival	MATC = > 100	Hansen et al., 1974a
--	42 days	Survival	MATC = < 32	Hansen et al., 1974a
2. Cyprinodon variegatus (sheepshead minnow)	28 days	Egg survival	MATC = > 100	Hansen et al., 1975
--	28 days	Fry, juvenile, and adult survival	MATC = 17.9	Hansen et al., 1975

Table 1. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1242		
Benthos				
1. P. pugio	96 hr	Survival	96 - hr LC50 = 26.4	Mayer, 1986
2. Uca pugilator (fiddler crab)	40 days	Molting rate	MATC = < 8,000	Fingerman and Fingerman, 1979
Fishes				
1. Fundulus grandis (Gulf killifish)	28 days	Rate of fin regeneration	MATC = > 8,000 ppb	Fingerman 1980 (First experiment)
		Aroclor 1254		
Phytoplankton				
1. Natural marine community in British Columbia, Canada (controlled 68-m^3 ecosystem)	24 hr	Primary productivity	MATC = < 50	Iseki et al., 1981
2. Natural marine community from Adriatic Sea (studied in laboratory)	6 hr	Photosynthesis	MATC = 3.2	Harding, 1976
3. Thalassiosira pseudonana (diatom)	48 hr	Cell division	MATC = < 10	Fisher, 1975

Table 1. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1254 (cont.)		
Phytoplankton (cont.)				
3. T. pseudonana (cont.)	72 hr	Cell division	MATC = < 1.0 - 3.2	Harding and Phillips, 1978a
--	72-120 hr	Cell division	MATC = 1.0	Fisher and Wurster, 1973
--	96 hr	Cell division	MATC = 22.4	Mosser et al., 1974
4. Rhizosolenia setigera (diatom)	144-192 hr	Cell division	MATC = < 0.1	Fisher and Wurster, 1973
5. Skeletonema costatum (diatom)	72 hr	Cell division	MATC = 3.2	Harding and Phillips, 1978a
6. Chaetoceros sociale (diatom)	72 hr	Cell division	MATC = 3.2	Harding and Phillips, 1978a
7. Dunaliella tertiolecta (green alga)	72-120 hr	Cell division	MATC = > 10	Fisher and Wurster, 1973
8. Isochrysis galbana (yellow-green alga)	72 hr	Cell division	MATC = < 1.0	Harding and Phillips, 1978a
9. Monochrysis lutheri (yellow-green alga)	72 hr	Cell division	MATC = 3.2	Harding and Phillips, 1978a
10. Coccolithus huxleyi	48 hr	Cell division	MATC = > 10	Fisher, 1975

Table 1. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1254 (cont.)		
Zooplankton				
1. Natural marine community in British Columbia, Canada (controlled 68-m^3 ecosystem)	15 days	Survival	MATC = < 50	Iseki et al., 1981
Benthos				
1. C. virginica	24 weeks	Growth	MATC = < 5	Nimmo et al., 1975
--	30 weeks	Growth	MATC = > 1	Nimmo et al., 1975
2. P. aztecus	2 weeks	Survival	MATC = 0.37	Nimmo et al., 1975
3. Penaeus duorarum (pink shrimp)	48 hr	Juvenile survival	MATC = 31.6	Duke et al., 1970
--	15 days	Juvenile survival	MATC = 0.73	Nimmo et al., 1971a
--	2 weeks	Survival	MATC = 0.73	Nimmo et al., 1975
--	17 - 53 days	Adult survival	MATC = < 2.4 - < 4.3	Nimmo et al., 1971a

Table 1. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1254 (cont.)		
Benthos (cont.)				
4. P. pugio	96 hr	Juvenile survival	96 - hr LC50 = 7	Roesijadi et al., 1976a
--	96 hr	Adult survival	96 - hr LC50 = 60	Roesijadi et al., 1976a
--	96 hr	Osmoregulatory mechanisms (hemolymph chloride, hemolymph osmotic conc., chloride space, chloride flux)	MATC = > 8.8 - > 76.4	Roesijadi et al., 1976b
--	96 hr	Osmoregulatory mechanism (free amino acids in muscle tissue)	MATC = > 29.4	Roesijadi et al., 1976c
5. Callinectes sapidus (blue crab)	2 weeks	Survival	MATC = 0.89	Nimmo et al., 1975
--	20 days	Juvenile survival	MATC = > 5.0	Duke et al., 1970
6. Gammarus oceanicus (amphipod)	30 days	Survival	MATC = 3.2 - 31.6	Wildish, 1970

Table 1. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1254 (cont.)		
Benthos (cont.)				
7. Arbacia punctulata (sea urchin)	72-73 hr	Fertilization efficiency	MATC = < 500	Adams, 1983
--	72-73 hr	Egg survival and larval development	MATC = 707	Adams, 1983
Fishes				
1. L. rhomboides	48 hr	Juvenile survival	MATC = > 100	Duke et al., 1970
--	14-35 days	Juvenile survival	MATC = < 5	Hansen et al., 1971
2. Leiostomos xanthurus (spot)	20-45 days	Survival	MATC = 2.2	Hansen et al., 1971
3. C. variegatus	1 day	Fertilization efficiency	MATC = > 10.0	Schimmel et al., 1974
--	7 days	Embryo development	MATC = 5.7	Schimmel et al., 1974
--	21 days	Fry survival	MATC = 0.18	Schimmel et al., 1974
--	21 days	Juvenile survival	MATC = 5.7	Schimmel et al., 1974
--	21 days	Adult survival	MATC = > 10.0	Schimmel et al., 1974

Table 1. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppb PCBs in water)[b]	Reference in scientific literature
		Aroclor 1254 (cont.)		
Fishes (cont.)				
4. F. grandis	28 days	Rate of fin regeneration	MATC = > 8,000 ppb	Fingerman 1980 (First experiment)
		Aroclor 1268		
Fishes				
1. F. grandis	28 days	Rate of fin regeneration	MATC = < 8,000 ppb	Fingerman 1980 (First experiment)

[a] All studies reviewed in this table were performed in the laboratory (under controlled experimental conditions) except when otherwise indicated (i.e., the studies by Iseki et al., 1981).

[b] Toxicological responses reported in this table are either the 96 hr-median lethal concentration (LC50) or maximum acceptable toxicant concentration (MATC), which is an exposure-time-specific toxicological statistic calculated as the geometric mean of the highest toxicant concentration that does not induce a toxicological response by test organism and the lowest toxicant concentration that does. A MATC value preceded by a "less-than" sign (<) indicates that toxicological response occurred at the lowest concentration of PCB tested, whereas a value preceded by a "greater-than" sign (>) typically signifies that the highest tested concentration did not elicit a toxicological response.

Aroclor 1016

Aroclor 1016 in water was acutely toxic to a variety of benthic invertebrates (American oyster, brown shrimp, and grass shrimp) at concentrations of approximately 10 ppb (Table 1; Hansen et al., 1974a). It was less toxic to fishes (pinfish and sheepshead minnows) even when those organisms were exposed to the formulation for lengthy periods of time. For example, MATC for survival of sheepshead minnow fry, juveniles, and adults exposed to Aroclor 1016 for 28 days was 17.9 ppb (Hansen et al., 1975). Also, MATC for acute (96-hr) survival of pinfish was >100 ppb PCBs, the highest concentration evaluated in the study (Hansen et al., 1974a).

Aroclor 1242

Aroclor 1242 tested in water with grass shrimp generated a 96-hr LC50 of 26.4 ppb (Table 1; Mayer, 1986), thus indicating an acute toxicity of less than one-half of the toxicity determined in a similar test with Aroclor 1016 (Table 1; Hansen et al., 1974a; grass shrimp; 96-hr LC50 = 12.5 ppb). Molting rate of fiddler crabs exposed to Aroclor 1242 for 40 days was inhibited at a concentration of 8,000 ppb (Fingerman and Fingerman, 1979), whereas rate of fin regeneration of gulf killifish was unaffected at the same concentration (Fingerman, 1980).

Aroclor 1254

Aroclor 1254 in water inhibited photosynthesis and/or cell division of various species of phytoplankton at concentrations ranging from 0.1 ppb (Table 1; Fisher and Wurster, 1973; R. setigera, a diatom) to about 22.4 ppb (Mosser et al., 1974; T. pseudonana, another diatom). However, Harding and Phillips (1978a) reported that some strains of estuarine phytoplankton are less sensitive to PCBs than marine varieties of the same species and concluded that "widespread inhibition of phytoplankton photosynthesis and cell division [has] probably not occurred [in the field] . . . ."

A natural community of zooplankton exposed to Aroclor 1254 for 15 days was eliminated at 50 ppb, the only concentration of PCBs tested (Table 1; Iseki et al.,

1981). Recovery of the community did not occur during the remaining 5 days of the investigation.

With regard to toxicity of Aroclor 1254 to benthos -- MATCs for growth of American oysters exposed to the formulation for 24 to 30 weeks ranged from > 1 to < 5 ppb PCBs (Table 1; Nimmo et al., 1975). MATCs for survival of several species of decapod crustaceans (brown shrimp, pink shrimp, and blue crabs) exposed to the formulation for 2 weeks were as low as 0.37 to 0.89 ppb PCBs (Nimmo et al., 1975). Amphipods and sea urchins appeared to be progressively less sensitive to Aroclor 1254 than decapod crustaceans. MATCs for 30-day survival of amphipods ranged from 3.2 to 31.6 ppb PCBs (Wildish, 1970); whereas MATCs for various vital biological functions of sea urchins were as high as 707 ppb PCBs (Adams, 1983).

Fishes (pinfish, spot, and sheepshead minnows) exposed to Aroclor 1254 were characterized by MATCs that, in general, were greater in magnitude than those observed for the sensitive decapod crustaceans -- i.e., MATCs for 14-45 day survival typically ranged from 2.2 to > 10.0 ppb PCBs (Table 1; Hansen et al., 1971; Schimmel et al., 1974). However, a 21-day study of survival of sheepshead minnow fry generated a MATC of 0.18 ppb PCBs (Schimmel et al., 1974). In an acute (48-hr) study of survival of juvenile pinfish, MATC was > 100 ppb PCBs (Duke et al., 1970). Finally, rate of fin regeneration of gulf killifish exposed to Aroclor 1254 for 28 days was not affected at a concentration of 8,000 ppb PCBs (Fingerman, 1980).

Aroclor 1268

Aroclor 1268 in water inhibited the rate of fin regeneration of gulf killifish exposed for 28 days to 8,000 ppb PCBs (Table 1; Fingerman, 1980).

1.1.2 PCBs in Sediment

Toxicity of several sediment-sequestered commercial formulations of PCBs -- a group of unspecified PCBs, Aroclor 1242 combined with Aroclor 1254, and Aroclor 1254 -- has been studied with a number of marine benthos and primarily demersal fishes (Table 2). The comparatively recent recognition of the

Table 2. ___ Toxicological responses of marine organisms exposed to polychlorinated biphenyls (PCBs) in sediment[a]

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppm PCBs in sediment, dry wt.)[b]	Reference in scientific literature
		Unspecified PCBs		
Benthos				
1. Uca minax (fiddler crab)	42 days	Survival	MATC = > 1.04	Clark et al., 1986
2. U. pugilator (fiddler crab)	28-42 days	Survival	MATC = > 0.97 - > 1.04	Clark et al., 1986
3. Natural infaunal community (Puget Sound, Southern California and New York Bights)	Chronic exposure	Tolerance by 95% of species	Screening Level Concentration (SCL) = 0.06[c]	Chapman et al., 1987
4. Natural infaunal community and benthos bioassays (Puget Sound)	Chronic and acute exposure	Statistically significant biological effects (versus reference conditions)	Apparent Effects Threshold (AET) = 0.13[c]	Chapman et al., 1987
Various benthos and fishes; benthos bioassays and bottomfish abnormalities (Puget Sound)	Chronic and acute exposure	Bioassay results and bottomfish data	Sediment Quality Triad = 0.1[c]	Chapman et al., 1987
		Aroclors 1242 and 1254		
Benthos				
1. Nereis virens (polychaete worm)	100 days	Survival	MATC = > 7.28 (metals documented in sediment)	Rubinstein, et al., 1983
2. Mercenaria mercenaria (hard clam)	100 days	Survival	MATC = > 7.28 (metals documented in sediment)	Rubinstein et al., 1983
3. Palaemonetes pugio (grass shrimp)	100 days	Survival	MATC = > 7.28 (metals documented in sediment)	Rubinstein et al., 1983

Table 2. __ Continued

Marine organism	Length of exposure period	Biological variable measured	Toxicological response of organism (ppm PCBs in sediment, dry wt.)[b]	Reference in scientific literature
		Aroclor 1254		
Benthos				
1. Penaeus sp. (penaeid shrimp)	3 weeks (upper Escambia Bay, Florida)	Survival	100% survival at sediment concentrations as high as 30 ppm	Nimmo et al., 1971a
2. Ampelisca abdita (amphipod)	10 days	Survival and emergence rate	MATC = >7.31 (metals documented in sediment)	Hansen et al., 1986 (Tests 1 and 2)[d]
--	10 days	Survival	MATC = > 66 (metals documented in sediment)	Hansen et al., 1986 (Tests 3 and 4)[d]
Fishes				
1. Parophrys vetulus (English sole)	108 days	Survival	MATC = > 2.2 (other organic constituents documented in sediment)	Stein et al., 1987
2. Cyprinodont variegatus (sheepshead minnow)	29 days	Survival and anomalies (F1 and F2 generations)	MATC = > 30.9 (metals documented in sediment)	Hansen et al., 1986[d]

[a] All studies reviewed in this table were conducted in the laboratory (under controlled experimental conditions) except when otherwise indicated (i.e., most of the studies reported by Chapman et al., 1987, and the study by Nimmo et al., 1971a).

[b] Toxicological responses reported in this table include the maximum acceptable toxicant concentration (MATC), which is an exposure-time-specific toxicological statistic calculated as the geometric mean of the highest toxicant concentration that does not induce a toxicological response by test organism and the lowest toxicant concentration that does. A MATC value preceded by a "less-than" sign (<) indicates that toxicological response occurred at the lowest concentration of PCB tested, whereas a value preceded by a "greater-than" sign (>) typically signifies that the highest tested concentration did not elicit a toxicological response.

[c] SCL, AET and Sediment Quality Triad are based upon results of correlation analyses of PCB concentrations in multi-constituent samples of sediment and associated toxicological responses of organisms and, consequently, cannot be assumed to represent causal relationships between PCB levels and toxicological responses.

[d] Studies reported by Hansen et al. (1986) were performed with sediments collected from inner New Bedford Harbor.

importance of sediment quality (in addition to water quality) to the well-being of marine organisms and the logical focus of this recognition on only those organisms most intimately associated with the sediment have resulted in a less-voluminous data base on the subject than in the case of water-borne PCBs.

It is important to emphasize that all of the sedimentary studies reviewed in Table 2 were performed with sediment that contained (or may have contained) a variety of potentially toxic constituents other than PCBs. Consequently, PCB-related MATCs identified in the table (i.e., the "greater-than" values) were derived from the most PCB-laden samples of sediment tested that did not cause toxicological responses by test organisms. Upper limits were not identified for these MATCs because toxicological responses associated with sediment samples containing higher concentrations of PCBs could not be assumed to exclusively reflect toxicity of the PCBs. However, several discrete (i.e., "non-openended") toxicological thresholds for PCBs -- a "Screening Level Concentration" (SCL), "Apparent Effects Threshold" (AET), and "Sediment Quality Triad" -- were reported by Chapman et al. (1987). These toxicological thresholds are based upon results of correlation analyses of PCB concentrations in multi-constituent samples of sediment and associated toxicological responses of organisms and, therefore, cannot be assumed to represent causal relationships between PCB levels and toxicological responses. Indeed, Chapman (1989) reported that the SCL, AET, and Sediment Quality Triad are currently in preliminary stages of development, are most reliably predicated upon large, typically area-specific, data bases, and are subject to bias by the presence in sediment of unmeasured toxic constituents that may or may not covary with measured constituents.

Unspecified PCBs

PCBs in sediment (mud and mud-sand) collected from New York Harbor were not toxic to two species of fiddler crabs exposed for up to 42 days to PCB concentrations ranging from 0.97 to 1.04 ppm, the highest concentrations evaluated during the study (Table 2; Clark et al., 1986). The authors of these studies reported that the PCBs were tightly bound to the "weathered" sediment and leached from the sediment very slowly, if at all (PCBs were not detected in water samples).

Natural infaunal benthic communities of Puget Sound, as well as Southern California and New York Bights, were reported to be chronically affected by sedimentary PCB concentrations greater than a SCL of 0.06 ppm (Table 2; Chapman et al., 1987). Similarly, the natural infaunal community of Puget Sound (studied, in part, through the use of laboratory bioassays) was reported to be affected by sedimentary PCB levels in excess of an AET of 0.13 ppm (Chapman et al., 1987). Finally, a variety of studies of benthos and bottom (demersal) fishes indigenous to Puget Sound indicated toxicological effects at PCB concentrations greater than a "sediment quality triad" of 0.1 ppm (Chapman et al., 1987). The above-identified area-specific, correlation-based, environmentally safe levels of sediment-associated PCBs, although relatively low, are consistent with results of studies reported by Pavlou (1987) for sediment containing 2% organic carbon. In those studies, which employed the equilibrium-partitioning approach in the context of a chronic water quality criterion of 0.014 ppb (a freshwater criterion), the safe level of PCBs in sediment was estimated to be 0.06 ppm (dry wt.). That safe level is at the low end of the range of historically reported safe threshold levels for PCBs in sediment -- 0.05 to 10 ppm, dry wt. (Pavlou, 1987).

Aroclors 1242 and 1254

Aroclors 1242 and 1254 present in sediment (clayey silt) collected from New York Harbor at a total concentration of 7.28 ppm were not toxic to several benthic invertebrates (polychaete worms, hard clams [quahogs], and grass shrimp) exposed to the formulations for 100 days (Table 2; Rubinstein et al., 1983). Since the sediment tested in these studies was reported to be contaminated with several metals, as well as PCBs, MATCs for PCBs may have been well in excess of 7.28 ppm.

Aroclor 1254

Aroclor 1254 was nontoxic to penaeid shrimp exposed for 3 weeks in cages to sediment in upper Escambia Bay, Florida, where PCB concentrations as high as 30 ppm have been reported (Table 2; Nimmo et al., 1971a). More important from the perspective of New Bedford Harbor, sediment collected from the inner harbor and tested for 10 days with amphipods generated MATCs for Aroclor

1254 that ranged from >7.31 to > 66 ppm (Hansen et al., 1986). The sediment employed in the study conducted by Hansen et al., (1986) contained various metals, and probably other xenobiotic constituents, in addition to PCBs.

English sole exposed for 108 days to Aroclor 1254 in sediment (42% silt) (Table 2; Stein et al., 1987) were characterized by a MATC of > 2.2 ppm (the only Aroclor concentration evaluated). A study by Hansen et al. (1986) of sheepshead minnows exposed for 29 days to sediment (which contained PCBs, metals, and probably other xenobiotic constituents) obtained from inner New Bedford Harbor generated a MATC for Aroclor 1254 of > 30.9 ppm.

1.1.3 PCBs in Food

One of the few studies reported in the scientific literature in which marine organisms exposed to PCBs in food were evaluated for toxicological effects (as contrasted to bioaccumulation of material) was performed with adult minnows (Phoxinus phoxinus) fed various doses of Clophen A50 (which contains approximately 50% chlorine by weight) for 40 days and observed for long-term sublethal effects for an additional 260 days (Bengtsson, 1980). MATCs (expressed in terms of PCB residues in whole-body tissues of fish, wet wt. measurement) were -- swimming ability of adults: > 170 - > 180 ppm adult body burden; hatching time for eggs: 5 ppm adult body burden; and hatchability of eggs: 50 ppm adult body burden. Body burdens of 180 ppm PCBs were associated with significantly increased growth of adult minnows.

1.2 Studies with Sediments from New Bedford Harbor

The previously referenced toxicological investigations in which amphipods and sheepshead minnows were exposed to sedimentary concentrations of Aroclor 1254 (Table 2; Hansen et al., 1986) were performed with material collected in the mid-1980s from inner New Bedford Harbor. Amphipods, which are surface-deposit and suspension feeders, were evaluated in two sets of tests. In the first set of tests (Tests 1 and 2), amphipods were exposed for 10 days to sediment (six samples of treatment sediment and control material) washed with flowing filtered seawater (approximately 13 exchanges per day). Treatment sediment was collected from inner New Bedford Harbor at four sampling stations

south of Interstate Route (I) 195 and at two stations north of I-195. The sediment samples contained a range of metal concentrations and a gradient of Aroclor-1254 levels -- Station 5: 7.31 ppm PCBs, dry wt.; Station 7: 13.3 ppm; Station 6: 19.3 ppm; Station 8: 30.9 ppm; Station 12: 231 ppm; and Station 14: 1,100 ppm. Biological responses of amphipods monitored during this set of tests were survival at Days 4 and 10 of tests and daily emergence of organisms from sediment (which is a sublethal indication of stress).

In the second set of amphipod tests (Tests 3 and 4), organisms were exposed for 10 days under dynamic (flow-through) conditions to treatment sediment (and dilutions of this sediment and control material) collected from several of the above-identified sampling stations (Station 5 and the heavily contaminated Stations 12 and 14). This set of tests was designed, in part, to evaluate the toxicological effects of metal concentrations in sediment in that material obtained from Station 12 and a 21% dilution of material from Station 14 were characterized by the same levels of Aroclor 1254 (231 ppm), but different levels of metals (approximately an order-of-magnitude more metals at Station 12). In addition, 14% of material from Station 12 and 3% of material from Station 14 were similarly paired (32-33 ppm Aroclor 1254 for both materials; about an order-of-magnitude more metals in the Station-12 dilution). Daily survival of amphipods was monitored during this study.

The amphipod investigation caused Hansen et al. (1986) to conclude that: 1) toxicity of sediment to organisms reflected a spatial gradient in the study area (i.e., sediment toxicity and "downstream" distance from the head of the Acushnet River Estuary were negatively correlated); 2) sediment from Station 14 (the station most contaminated with Aroclor 1254) had a "no-effect" concentration of 6% (i.e., 66 ppm) PCBs; and 3) sediment from Station 5 (7.31 ppm PCBs) was characterized by toxicity that was not significantly different from toxicity of control sediment. The effects of the presence of metals on toxicity of sediment are unclear. Although sediment from Station 12 and a 21% dilution of material from Station 14 (both materials contained 231 ppm PCBs) were comparable in toxicity despite their disparate levels of metals, results of the other paired toxicity tests (14% of sediment from Station 12 vs. 3% of material from Station 14) were not fully reported.

Hansen

Sheepshead minnows tested with sediment from inner New Bedford Harbor (Table 2; Hansen et al., 1986) were adult fish that were exposed for 29 days under apparently static (possibly static replacement) conditions to material collected from Stations 5 (7.31 ppm Aroclor 1254, dry wt.); 7 (13.3 ppm); 8 (30.9 ppm); 12 (231 ppm); and 14 (1,100 ppm). The fish were monitored for survival and several sublethal anomalies (fin rot and mouth erosion). At the end of the 29-day exposure period, surviving fish were induced to spawn and fertilized eggs of fish were transferred to uncontaminated flowing water, where developing embryos and fry were monitored for an additional 28 days for survival and, in the case of fry, fin rot. Results of the study caused Hansen et al. (1986) to conclude that : 1) adult fish exposed to sediments collected from above I-195 died (actually, survival of adult fish was 72% for Station 12 [231 ppm PCBs] and 0% for Station 14 [1,100 ppm PCBs]; in addition, an unexplained reference was made to a seemingly untested 28% dilution of material from Station 12); 2) survival of embryos and fry from adults exposed to sediments was reduced (actually, statistically significant reduced survival was only characteristic of young fish associated with sediment from Stations 12 and 14, the most contaminated stations); and 3) fin rot was common in surviving adult fish and their progeny (statistically significant increases in fin rot only occurred in adult fish exposed to sediment from Stations 12 and 14).

In the above-described study with sheepshead minnows, concentrations of Aroclor 1254 were reported (Hansen et al., 1986) just for sediment to which adult fish were intermittently exposed, not for associated water, with which fish had continuous contact. Since water apparently was not exchanged during the 29-day exposure period (or perhaps was exchanged to only a limited degree), aqueous levels of PCBs to which fish were exposed may have been higher than would occur in inner New Bedford Harbor. To evaluate this hypothesis, Enseco (1987) collected a sample of sediment from Station 14 (the most contaminated station evaluated in the sheepshead-minnow study) and established a 45-mm-thick layer of the material in each of two 19-liter (5-gal) aquaria (sedimentary material contained 4,500 ppm Aroclor 1242, dry wt.). Water was added to the aquaria to a depth of approximately 15 cm over the sediment layer. In one aquarium, initially added water was not replaced during a 28-day observation period; whereas, in the other aquarium, water was replaced by dynamic (flow-through) techniques at the rate of four volume changes per day. No animals

were placed in aquaria. In the static aquarium (which was designed to simulate exposure conditions in Hansen's sheepshead minnow study), aqueous concentrations of PCBs (reported as dissolved Aroclor 1242) averaged 91 ppb; whereas, in the dynamic aquarium, mean PCB level was 11 ppb. (In the case of both aquaria, PCB levels were highest at the start of the 28-day study and decreased dramatically by the end of the study.) The highest concentration of dissolved PCBs in the water of the upper Acushnet River Estuary was reported to be 4.0 ppb (Battelle, undated). Consequently, it is probable that results of the sheepshead minnow study are predicated upon unrealistically high aqueous levels of PCBs.

2. BIOACCUMULATION OF PCBs BY MARINE ORGANISMS

As in the case of the previously referenced toxicological investigations, studies of bioaccumulation of commercial formulations of PCBs by marine organisms have been performed primarily with Aroclor 1254, although some studies have been conducted with Aroclor 1016, Aroclor 1242, Aroclor 1260, and Phenoclor DP-5 (which was employed in several European studies). Unlike the toxicological investigations, bioaccumulation studies have also focused upon uptake of specific PCB congeners and isomers. Since chlorine content of PCBs and solubility of the materials in water is generally inversely related (e.g., Pavlou, 1987), a strictly physiochemical interpretation of the mechanics of bioaccumulation of PCBs suggests that the less chlorinated congeners (which are characteristic of the lower-series Aroclor formulations), in comparison to more chlorinated congeners, are more available in water for uptake by organisms, but, if bioaccumulated, are more likely to be depurated (eliminated from organisms).

It is important to emphasize that bioaccumulation of PCBs by marine organisms is not an indication of toxicity to the organisms. Indeed, the two phenomena are unlikely to represent concurrent aquatic hazards under stabilized environmental conditions -- i.e., high concentrations of toxic substances ultimately kill organisms, whereas only lesser levels of the substances (nonlethal levels) are associated with bioaccumulation. This principle is incorporated into the experimental design of most laboratory bioaccumulation tests, in which test organisms are exposed to concentrations of PCBs that are low enough to preclude the toxicity (certainly the mortality) that would render the tests useless. Correspondingly, body burdens of PCBs reported in organisms employed in laboratory bioaccumulation tests (at least long-term tests) are typically safe to the target organisms. These biologically safe body burdens can be quite high. For example, coho salmon (a freshwater life stage) that contained body burdens of up to 57.00 ppm Aroclor 1254 after being exposed to the formulation for 260 days exhibited no observable toxicosis, nor did channel catfish (a freshwater species) characterized by body burdens of up to 32.0 ppm Aroclor 1260 during a 193-day exposure period (Mayer et al., 1977).

Similarly, 28-day survival of juvenile sheepshead minnows containing body burdens of as much as 230 ppm (wet wt.) Aroclor 1016 was not significantly lower than survival of control fish; and up to 77 ppm Aroclor 1016 in eggs of adults did not affect survival of embryos or fry (Hansen et al., 1975). American oysters containing as much as 101 ppm (wet wt.) Aroclor 1254 were characterized by survival and growth that were comparable to control organisms during a 30-week monitoring period (Lowe et al., 1972). Spot (a fish) with body burdens of as much as 27 ppm (wet wt.) Aroclor 1254 were unaffected toxicologically during a chronic (140-day) bioaccumulation study (Hansen et al., 1971). Finally, as described in Section 1.1.3 of this document, MATCs for several vital biological functions of adult minnows exposed to Clophen A50 for 40 days and monitored for sublethal effects for an additional 260 days were (adult body burden of Clophen A50; ppm, wet wt.) -- swimming ability of adults: >170 - >180 ppm; hatching time for eggs: 5 ppm; and hatchability of eggs: 50 ppm (Bengtsson, 1980).

2.1 Experimental Studies with PCBs

Bioaccumulation studies have been conducted in which marine organisms were exposed to commercial formulations of PCBs and PCB-related congeners/isomers contained in water, sediment, and food. As in the case of toxicological studies, exposure of organisms to PCBs in one of these media frequently does not clarify whether associated media (e.g., interstitial water and overlying water in the case of bioaccumulation studies with layered sediment) are the vectors or routes of observed biological effects.

The importance of water, as compared to food (prey), as sources of PCBs in marine organisms has been extensively studied and debated without widespread agreement. Thomann (1981) concluded from a review of the scientific literature that PCB levels in top aquatic predators are due primarily to food-chain transfer (i.e., biomagnification) and derived a steady-state compartment food-chain model that suggested that PCB body burdens in top predators is due almost entirely to consumption of contaminated prey. His conclusions are based upon the observation that bioconcentration factors (BCFs; concentration of PCBs in organism, dry wt. ÷ concentration in water) observed in the field (which ranged from approximately 10,000 x to 10,000,000 x) were about

one order-of-magnitude higher than BCFs predicted by laboratory bioaccumulation tests (approximately 1,000 x to 1,000,000 x). Thomann surmised that the difference between observed and predicted factors was attributable to food consumption by fishes in the natural environment. Similarly, O'Connor and Pizza (1983) concluded from pharmacokinetic modeling efforts that steady-state burdens of PCBs in top-level predators (striped bass, winter flounder, and spot) inhabiting the New York Bight and adjacent waters were due primarily to food-chain transfer. Also, Goerke et al. (1979) associated trophic level (and lipid content of organisms) with higher PCB levels observed in fishes, as contrasted to bivalves, living in the Weser Estuary, Germany.

However, Tanabe et al. (1984) identified physiochemical mechanisms operating at lower trophic levels and several factors not including biomagnification (i.e., metabolic capacity and life span) functioning at higher trophic levels as explaining PCB increases they observed at upper levels of a four-species food chain (zooplankton, myctophid fish, squid, and a mammal, the striped dolphin) in the western North Pacific Ocean. Van den Broek (1979) emphasized lipid content of organisms as the basis of differences in PCB content of fishes and prey (brown shrimp) indigenous to the Medway Estuary, England. Shaw and Connell (1980) also implicated lipid content of organisms, rather than food-chain transfer, as influencing PCB levels in a multicomponent food web (a mollusk, several species of polychaete worms, three crustaceans, six fishes, and a bird) in the Brisbane River Estuary, Australia. Osterberg and Keckes (1977) reported that PCB concentrations actually decrease at successive food-chain levels in the Mediterranean Sea.

A panel of eminent marine scientists addressing acceptable levels of PCBs in the New York Bight (NOAA, 1977) commented on the "generally held belief" that levels of pollutants in gilled marine animals are controlled mostly by concentrations of the pollutants in water. The Office of Technology Assessment (1987) reported that bioaccumulation of organic chemicals depends primarily on the substances' ratio of lipid solubility to water solubility. Finally, Macek et al. (1979) concluded that, with the exception of DDT, "the process of biomagnification, as classically defined, probably does not occur within communities of aquatic organisms."

The importance of water versus sediment as sources of PCBs in marine organisms has received relatively little attention in comparison to studies of water versus food. The attention that has occurred naturally focused upon benthic organisms. Fresenius et al. (1984) reported that PCBs adsorbed to sediments have a low bioavailability to marine organisms in that bioaccumulation factors (BAFs; concentration of PCBs in organism ÷ concentration in sediment) typically range from less than 0.1 x to about 20 x, which are orders-of-magnitude lower than BCFs for organisms and water. Those investigators further elaborated that bioavailability of PCBs in sediment is directly related to water solubility of PCB congeners/isomers and sediment grain size, and inversely related to content of organic carbon in sediment and animal size. Courtney and Langston (1978) exposed two species of infaunal polychaete worms to Aroclor 1254 in seawater and sediment and, based upon the results of those paired exposures, concluded that benthic infauna of polluted aqueous environments (approximately 1 ppb PCBs) are not additionally affected by contaminated sediment (1 ppm PCBs on sand, dry wt.), but that, in less polluted water, fine sediments could sequester PCBs and thereby induce uptake of the materials by infauna. Also, Fowler et al. (1978) determined that sediments (9.3 - 80 ppm PCBs, dry wt.), as opposed to water (0.57 ppb PCBs), contributed the bulk of Phenoclor DP-5 to body burdens of polychaete worms. Most probable mechanisms suggested by Fowler for biological uptake of PCBs from sediment were ingestion of sediment by worms followed by absorption of PCBs through the gut, as well as absorption of PCBs from interstitial water through the cuticle (outside surface of worms).

2.1.1 PCBs in Water

Bioaccumulation of a number of water-borne commercial formulations of PCBs -- Aroclor 1016, Aroclor 1242, Aroclor 1254, Phenoclor DP-5, and Aroclor 1260 -- as well as several specific PCB congeners and isomers has been studied with various marine phytoplankton, benthos, and fishes (Table 3). BCFs (concentration of PCBs in organism, wet wt. ÷ concentration of PCBs in water) presented in this table are as high as 2,410,000 x, a value observed with phytoplankton. It is important to recognize that high BCFs typically reflect the extremely low concentrations of PCBs present in natural waters (usually at the parts-per-trillion level) as much as high concentrations of the substances in aquatic organisms. Also, in the case of phytoplankton, high BCFs may reflect

Table 3. __ Bioaccumulation of polychlorinated biphenyls (PCBs) by marine organisms exposed to material in water [a,b]

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in water	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioconcentration factor (BCF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Aroclor 1016				
Benthos							
1. Crassostrea virginica (American oyster)	84 days	10 ppb	130 ppm	13,000 x	56 days	100% loss	Parrish et al., 1974
Fishes							
1. Lagodon rhomboides (pinfish)	42 days	1 ppb	17 ppm	17,000 x	56 days	61% loss	Hansen et al., 1974a
2. Cyprinodon variegatus (sheepshead minnow)							
• Fry	33 days	0.32 - 32 ppb	0.81 - 200 ppm	2,500 x - 8,100 x	--	--	Hansen et al., 1975
• Juveniles	28 days	0.10 - 100 ppb	2.3 - 1,100 ppm	10,000 x - 34,000 x	--	--	Hansen et al., 1975
• Adults	28 days	0.10 - 10 ppb	0.84 - 110 ppm	4,700 x - 14,000 x	--	--	Hansen et al., 1975

Table 3. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in water	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioconcentration factor (BCF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Aroclor 1242				
Benthos							
1. Mytilus edulis (blue mussel)	--	--	--	--	89 days (in Puget Sound)	BHL = 8 days (initial tissue conc. = 0.070 ppm, wet wt.)	Calambokidis et al., 1979
			Aroclor 1254				
Benthos							
1. Nereis virens (polychaete worm)	12 - 48 hr	50 - 100 ppb (est.)	0.25 - 1.75 ppm	--	26 days	No loss	McLeese et al., 1980
2. C. virginica	24 - 30 weeks	1 - 5 ppb	101 - 425 ppm	85,000 x - 101,000 x	12-28 weeks	~ 100% loss	Lowe et al., 1972
3. M. edulis	--	--	--	--	89 days (in Puget Sound)	BHL = 23 days (initial tissue conc. = 0.360 ppm, wet wt.)	Calambokidis et al., 1979
4. Penaeus duorarum (pink shrimp)	22 days	2.5 ppb	~ 40 ppm	--	--	--	Nimmo et al., 1971a (Experiment 1)

Table 3. __ Continued

Marine organism	Uptake of material: Length of exposure period	Conc. in water	Conc. in organism (wet wt.)[c]	Bioconcentration factor (BCF)[d]	Depuration of material: Length of depuration period	Extent of depuration[e]	Reference in scientific literature
			Aroclor 1254 (cont.)				
Benthos (cont.)							
4. P. duorarum (cont.)	16 days	7.5 ppb	~ 10 ppm	--	5 weeks	No loss	Nimmo et al., 1971a (Experiment 2)
5. Palaemonetes pugio (grass shrimp)	3-5 weeks	0.04 - 0.62 ppb	0.2 - 10 ppm	--	4 weeks	Loss of "most" material (~ 50 - ~98% loss)	Nimmo et al., 1975
Fishes							
1. Leiostomus xanthurus (spot)	56 days	1 ppb	27 ppm	27,000 x	84 days	73% loss	Hansen et al., 1971
			Phenoclor DP-5				
Benthos							
1. Nereis diversicolor (polychaete worm)	2 weeks	0.57 ppb	~ 0.46 ppm	~ 800 x	--	--	Fowler et al., 1978

Table 3. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in water	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioconcentration factor (BCF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
				Aroclor 1260			
Benthos							
1. M. edulis	--	--	--	--	89 days (in Puget Sound)	BHL = 39 days (initial tissue conc. = 0.180 ppm, wet wt.)	Calambokidis et al., 1979
				2,3 - Dichlorobiphenyl			
Benthos							
1. C. virginica	28-65 days	~ 0.003 - ~ 0.009 ppb	~ 0.005 - ~ 0.01 ppm	1,200 x	--	--	Vreeland, 1974
				3,4,2' - Trichlorobiphenyl			
Benthos							
1. C. virginica	28-65 days	~ 0.003 - ~ 0.009 ppb	~ 0.02 - ~ 0.05 ppm	6,200 x	--	--	Vreeland, 1974

Table 3. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in water	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioconcentration factor (BCF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			2,5,2',5' - Tetrachlorobiphenyl				
Benthos							
1. C. virginica	28-65 days	~ 0.003 - ~ 0.012 ppb	~ 0.02 - ~ 0.08 ppm	7,400 x	--	--	Vreeland, 1974
			2,3,2',5' - Tetrachlorobiphenyl				
Benthos							
1. C. virginica	28-65 days	~ 0.003 - ~ 0.012 ppb	~ 0.03 - ~ 0.1 ppm	11,000 x	--	--	Vreeland, 1974
			2,4,5,2',5' - Pentachlorobiphenyl				
Phytoplankton							
1. 11 species	0.5 - 2.0 hr	0.31 - 9.86 ppb	3.8 - 6,084 ppm	12,300 x - 2,410,000 x	--	--	Harding and Phillips, 1978b
			2,3,4,2',5' - Pentachlorobiphenyl				
Benthos							
1. C. virginica	28-65 days	~ 0.001 - ~ 0.009 ppb	~ 0.02 - ~ 0.2 ppm	27,000 x	--	--	Vreeland, 1974

Table 3. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in water	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioconcentration factor (BCF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Penta- and Hexachlorobiphenyls				
Benthos							
1. Mytilus sp. (mussels)	Chronic exposure (French and California waters)	0.00068-0.0016 ppb	0.068 - 1.1 ppm	69,000 x - 690,000 x	--	--	Risebrough, et al., 1976
			2,4,5,2',4',5' - Hexachlorobiphenyl				
Benthos							
1. C. virginica	28-65 days	~ 0.001 - ~ 0.009 ppb	~ 0.02 - ~ 0.4 ppm	48,000 x	--	--	Vreeland, 1974
2. Strongylocentrotus purpuratus (purple sea urchin)	12 hr	0.38 - 10.01 ppb	0.012 - 0.059 ppm	--	6 hr	BHL = 8.66 - 15.75 days	Tjeerdema and Jacobs, 1987

[a] All studies reviewed in this table were performed in the laboratory (under controlled experimental conditions) except when otherwise indicated (i.e., the studies by Calambokidis et al., 1979 ,and Risebrough et al., 1976).

[b] The symbol "- -" indicates that a particular bioaccumulation-related measurement was not reported by author of original scientific article.

[c] Concentrations of material in organisms pertain to levels in "whole-body" tissues or muscle tissue.

[d] BCFs (conc. of material in organism ÷ conc. of material in water) are presented in this table only if they were derived by authors of original scientific articles and/or data appearing in the articles permit calculation of such factors for equilibrium conditions in both water and organism.

[e] Measurements of depuration (reduction in concentration of PCBs in tissues of organisms) include biological half-life (BHL), which is defined as the period of time required by an organism to reduce its body burden of PCBs by one-half of its original content.

PCBs adsorbed on the surface of the plants, as well as material incorporated into the body of the organisms.

Aroclor 1016

Aroclor 1016 in water at a concentration of 10 ppb caused American oysters exposed to the material for 84 days to accumulate body burdens of approximately 130 ppm PCBs, equivalent to a BCF of 13,000 x (Table 3; Parrish et al., 1974). However, oysters lost 100% of accumulated PCBs when placed in uncontaminated water for a period of 56 days. Fishes (pinfish and different life stages of sheepshead minnows) exposed to various levels of Aroclor 1016 for about 1 month were characterized by body burdens ranging from 0.81 to 1,100 ppm PCBs, and BCFs of from 2,500 x to 34,000 x (Hansen et al., 1974a; Hansen et al., 1975). Sheepshead minnows accumulated Aroclor 1016 in proportion to its concentration in test water, and pinfish lost 61% of accumulated body burdens during a 56-day depuration period.

Aroclor 1242

In the case of Aroclor 1242, blue mussels with relatively low body burdens of material (0.070 ppm PCBs) were characterized by a biological half-life (BHL) for the material of 8 days during a 89-day depuration period in Puget Sound (Calambokidis et al., 1979).

Aroclor 1254

Aroclor 1254 in water at concentrations of 50-100 ppb caused polychaete worms exposed to the material for just 12-48 hr to accumulate body burdens of 0.25 - 1.75 ppm PCBs (Table 3; McLeese et al., 1980). The worms did not depurate the material during a 26-day observation period. Similarly, pink shrimp exposed to 7.5 ppb Aroclor 1254 over a 16-day period exhibited no loss of accumulated material (approximately 10 ppm) during 5 weeks of depuration (Nimmo et al., 1971a; Experiment 2). Conversely, American oysters exposed for 24-30 weeks to 1-5 ppb Aroclor 1254 accumulated body burdens of 101-425 ppm PCBs (BCFs = 85,000 x - 101,000 x), but depurated essentially 100% of material during 12-28 weeks (Lowe et al., 1972). Blue mussels with low body

burdens of Aroclor 1254 (0.360 ppm) were characterized by a BHL for the material of 23 days (Calambokidis et al., 1979); and grass shrimp exposed for 3-5 weeks to comparatively low concentrations of Aroclor 1254 (0.04 - 0.62 ppb) lost about 50-98% of body burdens (0.2 - 10 ppm PCBs) during a 4-week depuration period (Nimmo et al., 1975).

Spot (a fish) exposed for 56 days to 1 ppb Aroclor 1254 (Table 3; Hansen et al., 1971) developed body burdens of 27 ppm PCBs (BCF = 27,000 x). However, 73% of PCBs was depurated over 84 days.

Phenoclor DP-5

Phenoclor DP-5 in water at a concentration of 0.57 ppb caused polychaete worms exposed to the material for 2 weeks to accumulate body burdens of approximately 0.46 ppm PCBs, equivalent to a BCF of about 800 x (Table 3; Fowler et al., 1978).

Aroclor 1260

In the last of three depuration studies with different Aroclor formulations and blue mussels (Table 3; Calambokidis et al., 1979), organisms exhibiting low body burdens of Aroclor 1260 (0.180 ppm) were characterized by a BHL for the material of 39 days.

PCB Congeners and Isomers

A series of comparable bioaccumulation tests with American oysters exposed to different PCB congeners generated the following BCFs -- dichlorobiphenyl: 1,200 x; trichlorobiphenyl: 6,200 x; tetrachlorobiphenyl (two different isomers): 7,400 x - 11,000 x; pentachlorobiphenyl: 27,000 x; and hexachlorobiphenyl: 48,000 x (Table 3; Vreeland, 1974). In these tests, bioaccumulation of congeners was proportional to concentration of the substances in test water, as well as degree of chlorination of the molecules (Vreeland, 1974).

Phytoplankton exposed for short periods (0.5 - 2.0 hr) to 0.31 - 9.86 ppb pentachlorobiphenyl were characterized by body burdens of from 3.8 to 6,084

ppm PCBs and associated BCFs ranging from 12,300 x to 2,410,000 x (Table 3; Harding and Phillips, 1978b). Mussels chronically exposed to extremely low concentrations of penta- and hexachlorobiphenyls (evidently, 0.00068 - 0.0016 ppb) in French and California waters developed relatively low body burdens of the substances (approximately 0.068 - 1.1 ppm PCBs), which, however, were equivalent to BCFs that ranged from 69,000 x to 690,000 x (Risebrough et al., 1976).

Minimal bioaccumulation of hexachlorobiphenyl was reported for purple sea urchins acutely exposed to the substance (Table 3; Tjeerdema and Jacobs, 1987). BHL for the 6-chlorine congener in sea urchins ranged from 8.66 to 15.75 days.

2.1.2 PCBs in Sediment

Bioaccumulation of several sediment-sequestered commercial formulations of PCBs -- a group of unspecified PCBs, Aroclor 1242, Aroclor 1242 combined with Aroclor 1254, Aroclor 1254, Phenoclor DP-5, and Aroclor 1260 -- has been investigated with a number of benthos and primarily demersal fishes (Table 4).

Unspecified PCBs

PCBs in sediment (and/or associated water) caused uncontaminated blue mussels transplanted for approximately 250 days at the hurricane barrier in New Bedford Harbor to accumulate body burdens of about 15 ppm PCBs on a dry-wt. basis (Table 4; Capuzzo et al., undated). These PCB burdens were greater than observed in mussels transplanted at two reference areas (Cleveland Ledge and Vineyard Sound).

Fiddler crabs exposed for 28 days to 0.37 - 1.04 ppm PCBs in sediment (mud and mud-sand) collected from New York Harbor accumulated PCBs to concentrations less than exposure levels (BAFs = 0.19 x - 0.79 x) and, during depuration periods of 14-21 days, rid their bodies of up to 100% of material (Table 4; Clark et al., 1986). Clark did not detect PCBs in water during these studies.

Table 4. __ Bioaccumulation of polychlorinated biphenyls (PCBs) by marine organisms exposed to material in sediment [a,b]

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Unspecified PCBs				
Benthos							
1. Mytilus edulis (blue mussel)	~250 days (hurricane barrier, New Bedford Harbor)	--	~15 ppm, (dry wt.)	--	--	--	Capuzzo et al., undated[f]
2. Uca minax (fiddler crab)	28 days	0.37 - 1.04 ppm	0.20 - 0.30 ppm	0.19 x - 0.79 x	21 days	100% loss	Clark et al., 1986
3. U. pugilator (fiddler crab)	28 days	0.37 - 1.04 ppm	0.21 - ~0.3 ppm	0.20 x 0.71 x	14 days	Substantial loss (up to 100%)	Clark et al., 1986
			Aroclor 1242				
Benthos							
1. Cerastoderma edule (cockle)	30 days	0.25 ppm (alumina particles in water)	27 ppm	107 x (wet wt. + wet wt.)	--	--	Langston, 1978a
--	10 days	0.25 ppm (alumina particles in water)	6.83 ppm	--	21 days	64% loss (BHL = 7-14 days	Langston, 1978b
2. Macoma balthica (tellin)	30 days	0.25 ppm (alumina particles in water)	61 ppm	243 x (wet wt. + wet wt.)	--	--	Langston, 1978a

Table 4. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Aroclor 1242 (cont.)				
Benthos (cont.)							
3. Mercenaria mercenaria (hard clam)	--	--	--	--	1 year (in outer New Bedford habor)	90% loss (initial tissue conc. = 4.16 ppm, wet wt.)	Deubert et al., 1981[f]
			Aroclors 1242 and 1254				
Benthos							
1. Nereis virens (polychaete worm)	30 - 40 days	0.46 - 7.82 ppm	~ 0.15 - ~ 0.5 ppm	~ 0.07 x - ~ 0.8 x (0.15 x - 1.59 x, wet wt. + wet wt.)	--	--	Rubinstein et al., 1983
2. M. mercenaria	38 days	0.46 - 7.82 ppm	~ 0.02 - ~ 0.12 ppm	~ 0.02 x - ~ 0.1 x	--	--	Rubinstein et al., 1983
3. Palaemonetes pugio	17 days	0.46 - 7.82 ppm	~ 0.03 - ~ 0.09 ppm	~ 0.01 x - ~ 0.1 x	--	--	Rubinstein et al., 1983

Table 4. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
				Aroclor 1254			
Benthos							
1. N. virens	32 days	0.03 - 0.58 ppm	0.13 - 3.5 ppm	-- (equilibrium estimated at ~ 78 days, 5.44 ppm boby burden, and BAF = 9.4 x)	--	--	McLeese et al., 1980
2. Nereis diversicolor (polychaete worm)	10 days	1 ppm	0.49 ppm	--	3 weeks	33% loss	Courtney and Langston, 1978
3. Arenicola marina (polychaete worm)	10 days	1 ppm	0.39 ppm	--	3 weeks	No loss	Courtney and Langston, 1978
4. M. edulis (blue mussel)	~ 20 days	1.07 ppm (sed. particles)	~ 0.115 ppm	~ 0.1 x	40 days	~ 60% loss	Pruell et al., 1986
5. M. mercenaria	--	--	--	--	1 year (in outer New Bedford harbor)	80% loss (initial tissue conc. = 0.70 ppm, wet wt.)	Deubert et al., 1981[f]
6. C. edule	30 days	0.25 ppm (alumina particles in water)	40 ppm	162 x (wet wt. + wet wt.)	--	--	Langston, 1978a

Table 4. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Aroclor 1254 (cont.)				
Benthos (cont.)							
6. C. edule (cont.)							
--	10 days	0.25 ppm (alumina particles in water)	20.54 ppm	--	21 days	0% loss	Langston, 1978b
7. M. balthica	30 days	0.25 ppm (alumina particles in water)	31 ppm	125 x (wet wt. + wet wt.)	--	--	Langston, 1978a
8. Crangon septem-spinosa (snapping shrimp)	32 days	0.08 - 0.13 ppm	0.22 - 0.60 ppm	1.7 x - 4.6 x	--	--	McLeese et al., 1980
9. U. minax	30 days	2.5 ppm	3.2 ppm	--	--	--	Nimmo et al., 1971b
--	30 days	4.9 ppm	3.6 ppm	--	--	--	Nimmo et al., 1971b
--	30 days	30.0 ppm	17.0 ppm	--	--	--	Nimmo et al., 1971b
--	30 days	61.0 ppm	80.0 ppm	--	--	--	Nimmo et al., 1971b
10. Rhepoxynius abronius (amphipod)	10 days	1.0 - 5.2 ppm	8.9 - 47 ppm	8.9 x - 9.0 x	--	--	Plesha et al., 1988

Table 4. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Aroclor 1254 (cont.)				
Fishes							
1. Parophrys vetulus (English sole)	108 days	2.2 ppm	0.110 ppm (dry wt.)	0.05 x (dry wt. + dry wt.)	--	--	Stein et al., 1987
2. Cyprinodon variegatus (sheepshead minnow)	29 days	7.31 ppm	15.6 - 21.0 ppm (dry wt.)	--	--	--	Hansen et al., 1986[f]
--	29 days	13.3 ppm	43.4 - 76.5 ppm (dry wt.)	--	--	--	Hansen et al., 1986[f]
--	29 days	30.9 ppm	59.0 - 73.8 ppm (dry wt.)	--	--	--	Hansen et al., 1986[f]
--	29 days	231 ppm	127 - 142 ppm (dry wt.)	--	--	--	Hansen et al., 1986[f]
--	11 days	1,100 ppm	100 - 107 ppm (dry wt.)	--	--	--	Hansen et al., 1986[f]

Table 4. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Phenoclor DP-5				
Benthos							
1. N. diversicolor	40 - 60 days	0.65 ppm	~ 0.7 ppm	~1.1 x	2 months	~ 50% loss (BHL = 27 days)	Elder et al., 1979
--	2 months	9.3 - 80 ppm	~ 15 - ~ 180 ppm	~ 1.6 x - ~ 2.2 x	65 days	~ 88% loss (initial tissue conc. = ~ 15 ppm wet wt.)	Fowler et al., 1978
			Aroclor 1260				
Benthos							
1. C. edule	30 days	0.25 ppm (alumina particles in water)	14 ppm	56 x (wet wt. + wet wt.)	--	--	Langston, 1978a
--	10 days	0.25 ppm (alumina particles in water)	5.03 ppm	--	21 days	0% loss	Langston, 1978b

Table 4. __ Continued

Marine organism	Uptake of material: Length of exposure period	Uptake of material: Conc. in sediment (dry wt.)	Uptake of material: Conc. in organism (wet wt.)[c]	Uptake of material: Bioaccumulation factor (BAF)[d]	Depuration of material: Length of depuration period	Depuration of material: Extent of depuration[e]	Reference in scientific literature
			Aroclor 1260 (cont.)				
Benthos (cont.)							
2. M. balthica	30 days	0.25 ppm (alumina particles in water)	14 ppm	56 x (wet wt. ÷ wet wt.)	--	--	Langston, 1978a

[a] All studies reviewed in this table were performed in the laboratory (under controlled experimental conditions) except when otherwise indicated (i.e., the studies by Capuzzo et al., undated, and Deubert et. al., 1981).

[b] The symbol "- -" typically indicates that a particular bioaccumulation-related measurement was not reported by author of original scientific article.

[c] Concentrations of material in organisms (wet wt. unless otherwise indicated) pertain to levels in "whole-body" tissues or muscle tissue.

[d] BAFs (conc. of material in organism, wet wt. ÷ conc. of material in sediment, dry wt., unless otherwise indicated) are presented in this table only if they were derived by authors of original scientific articles and/or data appearing in the articles permit calculation of such factors for equilibrium conditions in both sediment and organism.

[e] Measurements of depuration (reduction in concentration of PCBs in tissues of organisms) include biological half-life (BHL), which is defined as the period of time required by an organism to reduce its body burden of PCBs by one-half of its original content.

[f] Studies reported by Capuzzo et al. (undated); Deubert et al. (1981); and Hansen et al. (1986) were performed with sediments from New Bedford Harbor.

Aroclor 1242

Cockles (which are suspension-feeding bivalves) exposed for 30 days to alumina particles (0.25 ppm Aroclor 1242 in water) developed body burdens of 27 ppm PCBs, which is the equivalent of a BAF of 107 x on a wet wt. basis (Table 4; Langston, 1978a). In a similar experiment, tellins (deposit-feeding bivalves) were characterized by body burdens of 61 ppm Aroclor 1242 and a BAF of 243 x (Langston, 1978a). In both experiments, selective accumulation of moderately chlorinated (i.e., 5- chlorine) isomers was reported. In a depuration study with cockles, contaminated organisms (6.83 ppm Aroclor 1242) eliminated 64% of body burdens of PCBs (BHL = 7 - 14 days) during a 21-day period (Langston, 1978b). Elimination rates were reported to decrease with increased chlorination, and removal of isomers with more than 5-chlorine atoms was not observed. In addition, isomers with most "ortho"-substituted chlorine atoms were reported to be least persistent. This type of isomer is relatively volatile and soluble in organic matrices.

Contaminated hard clams (quahogs) from inner New Bedford Harbor (body burdens of 4.16 ppm Aroclor 1242) that were transplanted at an uncontaminated site in the outer harbor lost 90% of body burdens within a period of 1 year. (Table 4; Deubert et al., 1981). The predominance of Aroclor 1242 (as contrasted to Aroclor 1254, which was initially present at a concentration of 0.70 ppm) in undepurated clams was reported to be related to the relatively low chlorination of Aroclor 1242 isomers.

Aroclors 1242 and 1254

Several benthos (polychaete worms, hard clams, and grass shrimp) exposed for various lengths of time (17-40 days) to 0.46 - 7.82 ppm Aroclors 1242 and 1254 in sediment (clayey silt) collected from New York Harbor accumulated PCBs to concentrations less than exposure levels -- i.e., BAFs ranged from approximately 0.01 x to 0.8 x (Table 4; Rubinstein et al., 1983). Accumulation of PCBs by polychaetes was attributed to pathways in addition to direct uptake from water and was inversely correlated with organic content of sediment.

Aroclor 1254

Polychaete worms exposed for different periods of time (10-32 days) to ppm Aroclor 1254 in sediment were typically characterized by relatively low body burdens of PCBs (Table 4; McLeese et al., 1980; Courtney and Langston, 1978). In the uptake study with N. virens (McLeese et al., 1980), in which polychaetes were exposed to contaminated sand, equilibrium conditions were estimated to be 5.44 ppm body burden and an associated BAF of 9.4 x. Uptake of Aroclor 1254 by N. virens was reported to be directly related to PCB concentration in sediment and exposure time, and inversely related to polychaete size (small worms have a greater relative surface area than large worms and may have a greater metabolic rate). There was no selectivity reported for N. virens and specific PCB congeners. In two depuration studies conducted with polychaetes (Courtney and Langston, 1978), body burdens of Aroclor 1254, which were relatively low (0.39 - 0.49 ppm), were, at most, reduced by 33% during a 3-week observation period.

Blue mussels exposed for approximately 20 days to sedimentary particles containing Aroclor 1254 were characterized by a BAF of about 0.1 x and depurated approximately 60% of PCB body burden during a 40-day period (Table 4; Pruell et al., 1986). The distribution of PCBs in undepurated mussels was reported to be depleted in the highly chlorinated congeners relative to test sediment, and BHL of four measured congeners was -- 2,3,4′ trichlorobiphenyl: 16.3 days; 2,2′,4,5,5′ pentachlorobiphenyl: 27.9 days; 2,2′, 3, 3′, 4, 4′ hexachlorobiphenyl: 36.5 days; and 2,2′, 4,4′, 5,5′ hexachlorobiphenyl: 45.6 days. It appeared that PCBs passed through a dissolved phase during uptake by musselsm (Pruell et al., 1986).

Contaminated hard clams from inner New Bedford Harbor (body burdens of 0.70 ppm Aroclor 1254) that were transferred to an uncontaminated site in the outer harbor for 1 year lost 80% of PCB body burdens (Table 4; Deubert et al., 1981). BAFs for cockles and tellins exposed to Aroclor 1254 adsorbed onto alumina particles were, respectively, 162 x and 125 x on a wet wt. basis (Langston, 1978a). Selective uptake of 5-chlorine PCB isomers was reported to occur for both species. Cockles maintained accumulated body burdens of Aroclor 1254 (20.54 ppm) during a 21-day depuration period (Langston, 1978b).

Snapping shrimp exposed for 32 days to 0.08 - 0.13 ppm Aroclor 1254 in sediment (sand) were characterized by BAFs that ranged from 1.7 x to 4.6 x (Table 4; McLeese et al., 1980). Uptake of Aroclor 1254 by snapping shrimp was reported to be directly related to PCB concentration in sediment and inversely related to animal size. Less-chlorinated isomers represented the majority of accumulated PCBs (McLeese et al., 1980).

Fiddler crabs exposed for 30 days to sedimentary (silt and sandy silt) concentrations of Aroclor 1254 as high as 61.0 ppm (the sediment was collected from highly contaminated parts of Escambia Bay, Florida) accumulated body burdens of up to 80.0 ppm PCBs (Table 4; Nimmo et al., 1971b). Another type of crustacean, amphipods, exposed for 10 days to 1.0 - 5.2 ppm Aroclor 1254 in sediment (silty sand) was characterized by BAFs of 8.9 x - 9.0 x (Plesha et al., 1988). During the amphipod study, PCBs remained associated with the sediment (Plesha et al., 1988).

Fishes exposed to sedimentary levels of Aroclor 1254 include the English sole and sheepshead minnow (Table 4; Stein et al., 1987; Hansen et al., 1986). English sole exposed for 108 days to 2.2 ppm Aroclor 1254 in sediment (42% silt) were characterized by a BAF of 0.05 on a dry wt. basis (Stein et al., 1987). Sheepshead minnows exposed for 11-29 days to extremely high concentrations of Aroclor 1254 (7.31 - 1,100 ppm) in sediment collected from inner New Bedford Harbor accumulated body burdens of PCBs that were within one order-of-magnitude of levels of PCBs in sediment (Hansen et al., 1986).

Phenochlor DP-5

Polychaete worms chronically exposed (up to 2 months) in two different studies to a range of Phenoclor concentrations (0.65 - 80 ppm) in silty sediment accumulated body burdens of PCBs that were no more than a factor of approximately 2 x higher than levels of PCBs in sediment (Table 4; Elder et al., 1979; Fowler et al., 1978). Polychaetes rid their bodies of about 50-88% of accumulated PCBs during approximately 2 months in uncontaminated media. It was concluded (Fowler et al., 1978) that accumulation of PCBs from sediment was dose-dependent, and depuration of PCBs was concentration-dependent, with higher initial loss rates evident in polychaetes containing higher body

burdens of material. Also, sediment, as contrasted to water, contributed the bulk (85-99%) of PCBs to worms (Fowler et al., 1978). Most probable mechanisms for this phenomenon were reported to be absorption of PCBs from ingested sediment and/or uptake of material in interstitial water through the cuticle (outside surface of worms).

Aroclor 1260

Cockles and tellins exposed for 30 days to alumina particles (0.25 ppm Aroclor 1260 in water) were characterized by identical BAFs of 56 x (Table 4; Langston, 1978a). Selective uptake of 5-chlorine PCB isomers was observed for both species. Cockles maintained body burdens of Aroclor 1260 (5.03 ppm) during a 21-day depuration period (Langston, 1978b).

2.1.3 PCBs in Food

Transfer of Aroclor 1254 in a three-component marine food chain established in the laboratory was evaluated by Scura and Theilacker (1977). The marine organisms constituting the food chain were -- primary producer: algal flagellate (Dunaliella sp.); primary consumer (herbivore): rotifer (Brachionus plicatilis); and secondary consumer (low-level carnivore): larva of northern anchovy (Engraulis mordax). Water to which algae (and rotifers) were exposed contained from 0.0026 to 0.0136 ppb Aroclor 1254, which was representative of PCB levels in near-shore waters off of southern California. (Anchovies were maintained in water containing 0.002 ppb Aroclor 1254.) Concentrations of Aroclor 1254 in algae, which appeared to reach steady-state levels within 5 days after exposure of organisms to test material, ranged from 0.12 to 0.38 ppm, dry wt. Concentrations of Aroclor 1254 in consumers, which also reached equilibrium within 5 days of the time that consumers were initially fed prey, ranged from 0.29 to 0.54 ppm for rotifers and 1.11 to 2.67 ppm for fish.

Although the above-described body burdens of Aroclor 1254 in the three test organisms suggest amplification of PCBs in a step-wise fashion up the food chain (i.e., biomagnification), supplemental studies performed by Scura and Theilacker (1977) indicated that such was not the case. When concentrations of PCBs in algae and rotifers were converted from a whole-body to lipid basis,

differences between the two species were no longer evident -- i.e., what appeared to be biomagnification was simply a reflection of the greater lipid content of rotifers. In the case of the last link in the evaluated food chain -- anchovy lipids contained a substantially higher concentration of PCBs (27.46 ppm) than rotifer lipids (2.80 ppm) but, in additional tests, PCB levels in lipids of unfed anchovies maintained in contaminated water (0.0025 - 0.0045 ppb PCBs) ranged from 37.33 to 62.67 ppm. Consequently, the conclusion reached in this investigation was that PCB accumulation is not a food-chain phenomenon, but, rather, is the result of direct partitioning of the compounds between seawater and marine organisms.

2.2 Studies with Sediments from New Bedford Harbor

The previously referenced bioaccumulation studies (Table 4) by Capuzzo et al. (undated), Deubert et al. (1981), and Hansen et al. (1986) were performed with sediment in or collected from New Bedford Harbor

Capuzzo et al. (undated) reported that uncontaminated blue mussels transplanted for approximately 250 days (November 1984-July 1985) at the hurricane barrier in New Bedford Harbor attained body burdens of PCBs that approximated 15 ppm dry wt., which was about one order-of-magnitude higher than in mussels maintained for the same period of time at two reference areas (Cleveland Ledge and Vineyard Harbor). Mussels deployed in New Bedford Harbor were characterized by considerable initial uptake followed by gradual stabilization of all chlorobiphenyls evaluated. Superimposed upon that basic pattern was fluctuation in concentrations of some chlorobiphenyls during late spring and summer and a marked decline in levels during autumn, which were associated with gametogenesis and spawning activity. (Condition index of mussels was inversely correlated with body burdens of PCBs.)

The pattern of PCB distribution in mussels transplanted in New Bedford Harbor was substantially different from patterns at the reference areas. In particular, one of the least chlorinated PCBs monitored during the study (2, 4, 4′-trichlorobiphenyl) was the second most abundant isomer present in harbor mussels (2,2′, 3, 5′, 6-pentachlorobiphenyl was most abundant) and, in

comparison to more highly chlorinated PCBs, was present in greater relative abundance in harbor mussels than in reference animals. The predominance of this trichlorobiphenyl in harbor mussels, notwithstanding its comparatively low octanol-water partition coefficient (K_{ow}) and, hence, supposedly low physiochemical potential to accumulate in organisms (Capuzzo et al., undated), was explained on the basis of its typically high concentrations in harbor water relative to the more chlorinated PCBs with high K_{ows}. Thus, the hypothesis was posed that body burdens of PCBs in harbor mussels were primarily dependent upon PCB concentrations in water, modified to some extent by partitioning between water and organisms.

Deubert et al. (1981) measured concentrations of PCBs (Aroclors 1242 and 1254) in hard clams collected on October 12, 1978, from two locations (Stations "D" and "E") just north of the hurricane barrier in inner New Bedford Harbor, as well as in clams obtained from four areas (Stations "A", "C", "F", and "G") in the outer harbor. Body burdens of PCBs in clams from the inner harbor ranged from 2.50 to 4.86 ppm, wet wt.; while body burdens of animals from the outer harbor were from 0.35 to 6.93 ppm. Body burdens of outer-harbor clams had not decreased significantly (in a statistical sense) from burdens observed in 1976.

Hard clams collected from locations closest to the supposed sources of PCB contamination and containing the highest total body burdens of PCBs were characterized by the highest concentrations of Aroclor 1242 relative to levels of Aroclor 1254. However, patterns of PCB isomers in those clams were not identical to patterns in Aroclor mixtures that had been employed for industrial purposes, and Aroclor 1242 was predominant over Aroclor 1254 in clams obtained from all sampling locations. These occurrences were attributed to the less chlorinated nature of Aroclor 1242 (versus Aroclor 1254) and, presumably, its greater water solubility and potential availability to clams; selective degradation of PCB isomers in the environment; and selective uptake of the isomers by clams.

Hard clams collected from one of the locations just inside the hurricane barrier (Station "D") were transplanted at an uncontaminated site located approximately 14 km (9 miles) from the contaminated area and monitored for body burdens of PCBs over a period of 1 year. During that time, body burdens of

Aroclors 1242 (4.16 ppm) and 1254 (0.70 ppm) decreased by, respectively, 90 and 80%.

Hansen et al., (1986) conducted a laboratory bioaccumulation study in which adult sheepshead minnows were exposed to sediment collected in the mid-1980s from a number of locations in inner New Bedford Harbor. The locations and associated sedimentary concentrations of Aroclor 1254 were -- Station 5: 7.31 ppm, dry wt.; Station 7: 13.3 ppm; Station 8: 30.9 ppm; Station 12: 231 ppm; and Station 14: 1,100 ppm. Fish were typically exposed to sediment for 29 days (exposure to the most contaminated sediment sample was only 11 days), and water in test aquaria apparently was not exchanged during the exposure period (the tests possibly were performed under static, replacement conditions). At the end of the 29-day (or 11-day) exposure period, fish had accumulated body burdens of Aroclor 1254 that generally approximated levels in sediment to which fish were exposed (Table 4; Hansen et al., 1986). However, at the lowest test concentration (7.31 ppm PCBs in sediment), body burdens of fish were an order-of-magnitude higher (15.6 - 21.0 ppm PCBs, dry wt.); while, at the highest test concentration (1,100 ppm PCBs in sediment), body burdens of organisms were an order-of-magnitude lower (100 - 107 ppm PCBs).

With regard to composition of PCB body burdens in sheepshead minnows, tetra- and pentachlorobiphenyls were commonly associated with all sampling locations. However, body burdens of fish exposed to sediment from the most "upstream" location (Station 14, located nearest to one potential industrial source of PCBs and characterized by the highest observed sedimentary concentration of PCBs [1,100 ppm]) consisted mostly of trichlorobiphenyls (42% of total body burdens) followed by dichlorobiphenyls (30% of total burdens). (These lightly chlorinated congeners, although common components of Aroclors 1016 and 1042, are not characteristic of Aroclors 1254 and 1260.) Conversely, the more chlorinated congeners (in particular, penta-, hexa-, and heptachlorobiphenyls) were underrepresented in body burdens of fish relative to concentrations in sediment.

Results of the bioaccumulation study with sheepshead minnows caused Hansen et al. (1986) to conclude that: 1) PCB concentrations in adult fish were similar to levels in sediments; 2) predominance of less chlorinated PCB

congeners in fish relative to sediment suggests that fish were not exposed to sediment for sufficient periods of time; 3) PCB concentrations in eggs produced by adult females were slightly lower than levels in females; and 4) metals (which were also evaluated during the study) were not accumulated from sediment by adult fish. As discussed in Section 1.2 of this document, sheepshead minnows were probably exposed to environmentally unrealistic concentrations of water-borne PCBs during this study.

3. RELATIVE TOXICITY AND BIOACCUMULATION POTENTIAL OF DIFFERENT PCB AROCLORS TO MARINE ORGANISMS

Limited information exists in the scientific literature pertaining to relative toxicological and bioassimilative properties of different Aroclor formulations in the marine environment. Much of the comparative information that does exist was not generated in "paired" or "matched" tests performed under identical experimental conditions, but, rather, was gleaned from various similar tests (sometimes conducted by different laboratories) that, collectively, addressed two or more Aroclor formulations.

Most of the toxicological and bioaccumulation-related information presented below is contained in Table 1 (toxicological data) or Tables 3 and 4 (bioaccumulation data). Those data are simply presented in a different format in this section of the document to facilitate comparisons of different Aroclor formulations.

3.1 Toxicity

The limited information concerning the relative toxicity of various Aroclors to marine organisms suggests that, in general, the less-chlorinated Aroclors (e.g., Aroclors 1016 and 1242) are less toxic to organisms than the more-chlorinated formulations (e.g., Aroclors 1254 and 1260).

Grass shrimp exposed to Aroclor 1016 (Hansen et al., 1974a) and Aroclor 1242 (Mayer, 1986) in water were characterized by 96-hr LC50s of 12.5 and 26.4 ppb, respectively. Shrimp tested with Aroclor 1254 (Roesijadi, 1976a) generated 96-hr LC50s of 7 ppb (juvenile organisms) and 60 ppb (adults). Consequently, little can be concluded from these data regarding comparative toxicities of different formulations of Aroclors to grass shrimp. Similarly, MATC for 96-hr survival of pinfish exposed to Aroclor 1016 was > 100 ppb (Hansen et al., 1974a), whereas MATC for 48-hr survival of juvenile pinfish tested with Aroclor 1254 was also > 100 ppb (Duke et al., 1970). Of course, it cannot be determined

if this latter MATC would have decreased (indicating increased toxicity) to < 100 ppm if exposure period had been extended to 96 hr, as was the case for pinfish exposed to Aroclor 1016. However, juvenile pinfish exposed for 14-35 days to Aroclor 1254 (Hansen et al., 1971) were characterized by a MATC (for survival) of < 5 ppb; whereas pinfish tested for a longer period of time (42 days) with Aroclor 1016 (Hansen et al., 1974a) exhibited a MATC (for survival) of < 32 ppb. These data suggest that Aroclor 1016 is less toxic to pinfish than Aroclor 1254.

Sheepshead minnows exposed for 28 days to Aroclor 1016 in water were characterized by a MATC (for survival of fry, juveniles, and adults) of 17.9 ppb (Hansen et al., 1975), as compared to 21-day MATCs for Aroclor 1254 (Schimmel et al., 1974) of 0.18 ppb (survival of fry), 5.7 ppb (survival of juveniles), and > 10.0 ppb (survival of adults). This set of data apparently caused Hansen et al. (1975) to conclude that Aroclor 1016 "is about [100 times less toxic than] Aroclor 1254 to sensitive fry."

Lastly, gulf killifish exposed for 28 days to various Aroclors in water (Fingerman, 1980) were characterized by MATCs (for rate of fin regeneration) of -- Aroclor 1016: > 8,000 ppb; Aroclor 1254: > 8,000 ppb; and Aroclor 1268: < 8,000 ppb. This set of toxicological data distinguishes between the lesser toxicity of Aroclors 1016 and 1254, as compared to the greater toxicity of Aroclor 1268.

Relative toxicity of different Aroclors to freshwater organisms (a less germane subject than toxicity to marine organisms) was reported by Mayer et al. (1977). Acute tests with cutthroat trout generated 96-hr LC50s of -- Aroclor 1242: 5,400 ppb; Aroclor 1254: 42,000 ppb; and Aroclor 1260: 61,000 ppb (these valves are substantially higher than the solubilities of the various Aroclors in water). Crayfish acutely exposed to Aroclors 1242 and 1254 were characterized by LC50s of 30 and 100 ppb, respectively. A series of chronic toxicity tests with rainbow trout, bluegills, and channel catfish indicated that Aroclor 1248 was more toxic than less-chlorinated (Aroclor 1242) and more-chlorinated (Aroclors 1254 and 1260) PCBs.

3.2 Bioaccumulation Potential

The information available regarding the relative potential of individual Aroclors to bioaccumulate in marine organisms indicates that biological uptake and depuration of the formulations are typically influenced by both general physiochemical and species-specific factors. In the case of uptake of Aroclors, major physiochemical factors include concentrations and solubilities of associated isomers in environmental media to which organisms are exposed, and species-specific considerations include preferential assimilation of particular isomers depending upon the degree and position of chlorine substitution. Depuration of Aroclors is dependent upon concentrations (i.e., body burdens) of isomers bioaccumulated, solubilities of the substances, and preferential species-specific metabolism of the chemicals. To the extent that physiochemical factors predominate over species-specific processes, the less chlorinated (and more water-soluble) Aroclors (e.g., Aroclors 1016 and 1242) generally would be expected to be more readily available to aquatic organisms for uptake and, if bioaccumulated, more rapidly depurated by organisms than the more chlorinated (and less water-soluble) formulations (e.g., Aroclor 1260).

American oysters exposed for 84 days to 10 ppb Aroclor 1016 in water were characterized by a BCF of 13,000 x (Parrish et al., 1974), while oysters exposed for at least twice that time (24-30 weeks) to lower concentrations (1-5 ppb) of Aroclor 1254 generated BCFs of 85,000 x - 101,000 x (Lowe et al., 1972). In addition, both sets of oysters depurated essentially 100% of body burdens of PCBs within 56 days (Aroclor 1016) and 12-28 weeks (Aroclor 1254) after being placed in uncontaminated water. The different exposure times and concentrations employed in the two oyster tests preclude reliable comparisons of biological uptake between Aroclors 1016 and 1254. However, the most dramatic information obtained from the two tests is that oysters have the capability of completely eliminating both Aroclor 1016 and Aroclor 1254 from their bodies (elimination of Aroclor 1016 occured more rapidly).

Blue mussels that contained relative low body burdens of Aroclors 1242 (0.070 ppm), 1254 (0.360 ppm) and 1260 (0.180 ppm), and which were allowed to depurate for 89 days, were characterized by BHLs of -- Aroclor 1242: 8 days; Aroclor 1254: 23 days; and Aroclor 1260: 39 days (Calambokidis et al., 1979).

These data clearly document an inverse relationship between chlorine content of Aroclors and depuration rates by mussels.

Tellins exposed for 30 days to 0.25 ppm Aroclors 1242, 1254, and 1260 adsorbed on alumina particles in water exhibited BAFs of -- Aroclor 1242: 243 x; Aroclor 1254: 125 x; and Aroclor 1260: 56 x (Langston, 1978a). Similarly, cockles treated under identical experimental conditions generated BAFs of -- Aroclor 1242: 107 x; Aroclor 1254: 162 x; and Aroclor 1260: 56 x (Langston, 1978a). These data, considered collectively, indicate that the less chlorinated Aroclors 1242 and 1254 are accumulated by tellins and cockles to a greater degree than the more chlorinated Aroclor 1260. With regard to depuration of PCBs, cockles lost 64% of their body burden of Aroclor 1242 within 21 days of being placed in uncontaminated water (BHL = 7-14 days), whereas organisms lost none of their body burdens of Aroclors 1254 and 1260 under comparable experimental conditions (Langston, 1978b).

Hard clams that contained body burdens of 4.16 ppm Aroclor 1242 and 0.70 ppm Aroclor 1254 after being exposed to the materials in sediment located just inside the hurricane barrier in New Bedford Harbor, and which were placed in an uncontaminated environment in outer New Bedford Harbor for 1 year, lost 90% of their body burden of Aroclor 1242 and 80% of their burden of Aroclor 1254 (Deubert et al., 1981). Although these data superficially indicate a slightly greater potential of clams to depurate the less chlorinated Aroclor 1242 than the more chlorinated Aroclor 1254, this seeming phenomenon may be an artifact associated with the higher initial body burden of Aroclor 1242 in the organisms.

Finally, small American oysters exposed for 28-65 days to low concentrations (approximately 0.001-0.012 ppb) of specific PCB congeners in water were characterized by the following BCFs -- dichlorobiphenyl: 1,200 x; trichlorobiphenyl: 6,200 x; tetrachlorobiphenyl: 7,400 x - 11,000 x; pentachlorobiphenyl: 27,000 x; and hexachlorobiphenyl: 48,000 x (Vreeland, 1974). These data suggest a positive relationship between chlorine content of Aroclors and uptake by oysters. However, since studies of this nature (studies in

which PCB concentrations in organisms are at equilibrium with levels in water) reflect outward, as well as inward, transport of PCBs, the data may simply document the persistence of the more highly chlorinated congeners in tissues of the organisms.

4. SITE-SPECIFIC EXPOSURE CONSIDERATIONS FOR MARINE ORGANISMS

New Bedford Harbor received effluent discharges of PCBs from two electrical-capacitor manufacturing plants during the late 1940s into the 1970s. One of these plants was located approximately 2.1 km (3.4 miles) north of Interstate I-195 in the upper Acushnet River Estuary, while the other plant was situated about 1.2 km (0.7 miles) south of the hurricane barrier in outer New Bedford Harbor. The plant in the Acushnet River Estuary employed Aroclors 1016 and 1242 (approximately 75% of total PCBs utilized) and Aroclor 1254 (25% of PCBs used) in its operations, although it employed Aroclor 1016 exclusively after 1971. Additional sources of PCBs to New Bedford Harbor include the atmosphere and local marine operations (Brownawell, 1986) and, possibly, a nearby spoil area (Kolek and Ceurvels, 1981).

PCBs in environmental media collected from New Bedford Harbor have typically been identified as Aroclors 1242 and/or 1254. In general, media from the inner harbor north of I-195 (i.e., the Acushnet River Estuary) have contained approximately equal amounts of Aroclor 1242 and Aroclor 1254, with the relative proportion of Aroclor 1242 decreasing as a function of increasing distance from the estuarine area (Farrington et al., 1983). This trend was reported to be consistent with the relative environmental instability (e.g., relative solubility in water) of the less-chlorinated congeners (bi-, tri-, and tetrachlorobiphenyls) that characterize Aroclor 1242.

A substantial amount (upwards of perhaps 100 metric tons) of PCBs has been reported (Farrington et al., 1983) to be contained in the upper sediment of the Acushnet River Estuary. Much of this mass occurs in a limited area of the upper estuary that has been termed the "Hot Spot" (Ebasco Serv., 1989). The Hot Spot actually consists of four discrete areas totaling approximately 2 hectares (5 acres) that are located in the mudflats and sediments along the western bank of the upper estuary (Ebasco Serv., 1989). Sedimentary concentrations of PCBs at the Hot Spot characteristically range from 0 to > 4,000 ppm (dry wt.), but have

been reported to be as high as 249,000 ppm (Ebasco Serv., 1989). PCB contamination at the Hot Spot extends to a sediment depth of approximately 1 m (3 ft) and constitutes about 45% of the total PCB mass in the New Bedford Harbor area (Ebasco Serv., 1989).

PCBs in New Bedford Harbor are continuously being diminished or degraded by a variety of natural processes that include "dilution" of PCB-laden sediment by uncontaminated sediment, microbial degradation of PCBs present in all environmental media, as well as photo-oxidation and volatilization of PCBs in the water column. Dilution of PCB-containing sediment by uncontaminated material (and/or "leaching out" of PCBs from surficial sediment) is suggested by sediment profiling studies conducted in the southern part of the inner harbor and the outer harbor (Brownawell, 1986). These studies documented maximum PCB concentrations at approximately 15 cm below the sediment-water interface. The attenuation of PCB-contaminated sediment by newly deposited material may be greatest in the northern part of the inner harbor (i.e., the Acushnet River Estuary), which is a depositional area for suspended materials transported from Buzzard's Bay (Teeter, 1988).

PCB concentrations in marine and estuarine environments and numbers of PCB-degrading bacteria have been demonstrated to exhibit a positive relationship, and both PCBs and PCB-degrading organisms have been observed at higher concentrations in estuarine, as contrasted to marine, environments (Sayler et al., 1978). Aerobic microbial degradation of PCBs has been extensively investigated and found to be dependent upon the degree and position of chlorine substitution (Brownawell, 1986). For example, marine bacteria exposed to tetrachorobiphenyl in seawater were characterized by 2-4% metabolism within 3 days of inoculation, a metabolic level that did not increase during the next few weeks (Carey and Harvey, 1978). More recently, anaerobic microbial metabolism was implicated in decreases of highly chlorinated PCBs in severely contaminated sediment from the Hudson River and New Bedford Harbor (Brown and Wagner, 1986).

Photo-oxidation and volatilization of PCBs are typically water-column phenomena and are likely to be most operative in the case of less chlorinated PCBs (Farrington et al., 1986). Since both phenomena exhibit maximum

efficiency in shallow waters, they may play a material role in reducing PCB concentrations in the neritic waters of New Bedford Harbor. In addition, the duel processes may be effective in attenuating PCB levels in the mudflats of the upper estuary (i.e., the Hot Spot area) when the flats are exposed to the atmosphere during low tides.

The multiple input, transport, and diminishment/degradation processes that characterize PCBs in New Bedford Harbor have resulted in the environmental concentrations of material that are reviewed in Table 5. Surficial sediment in the northern part of the inner harbor (i.e., the Acushnet River Estuary) has been characterized by PCB concentrations that varied from 100 to > 1,000 ppm (Farrington et al., 1986), although PCB levels in sediment at the Hot Spot were substantially in excess of the absolute upper limit of this range. (Ebasco Serv., 1989). However, in the southern part of the inner harbor, sedimentary concentrations of PCBs typically ranged from 1 to 100 ppm; while in the outer harbor, PCB levels of from < 1 to 50 ppm usually prevailed (Farrington et al., 1986). (High sedimentary levels of PCBs in the outer harbor were generally confined to the area proximal to the old discharge points for one of the two electrical-capacitor manufacturing plants.)

Interstitial water (i.e., sediment pore water) at two sampling locations in New Bedford Harbor contained PCB concentrations (maximum of 1.57 to 20.13 ppb) that were substantially higher than proximal water-column levels (Table 5; Brownawell, 1986), which indicated (Brownawell, 1986) that a large fraction of the interstitial PCBs was sorbed to organic colloids. The disparity between PCB levels in interstitial water and overlying water was reported to be particularly pronounced in the case of the more chlorinated (less water-soluble) chlorobiphenyls.

The water column of the northern part of the inner harbor has been characterized by concentrations of dissolved PCBs that ranged up to 4.0 ppb (Table 5; Battelle, undated), which is less than the acute water quality criterion for the protection of marine organisms (10 ppb; EPA, 1986). Levels of dissolved PCBs in the water column of the southern part of the inner harbor and the outer harbor are substantially lower as evidenced by the levels reported by Brownawell (1986) -- 0.170 ppb for the inner harbor and 0.011 - 0.020 ppb for the

Table 5. __ Concentrations of polychlorinated biphenyls (PCBs) in environmental media collected from New Bedford Harbor

Location of collection	Date of collection	Concentration of PCBs in environmental medium	Reference in scientific literature
		Surficial Sediment	
Inner harbor north of I-195 (whole area)	1970s-early 1980s	100 - > 1,000 ppm (Aroclor 1254, dry wt.)	Farrington et al., 1986
-- (Stations 12 and 14)	Mid-1980s	231 - 1,100 ppm (Aroclor 1254, dry wt.)	Hansen et al., 1986
-- (Stations 12, 13, and 14)	1986 (Jan. 21-22)	151 - 540 ppm (Aroclor 1254, dry wt.)	HMM Assoc., 1986
-- (Stations 12, 14, and 15)	1987 (Dec. 30)	40 - 4,500 ppm (Aroclor 1242, dry wt.)	Enseco, 1987
-- (whole area)	1970s - late 1980s	0 - > 4,000 ppm (total PCBs, dry wt.); max. conc. = 249,000 ppm	Ebasco Serv., 1989
Inner harbor south of I-195 (whole area)	1970s-early 1980s	1 - 100 ppm (Aroclor 1254, dry wt.)	Farrington et al., 1986
-- (Station 84)	1981 (Oct. 29)	108 ppm max. at sediment depth of 12-15 cm(Aroclors 1242 [43%] and 1254 [57%], dry wt.); decrease to 0.1 ppm at 27-30 cm	Brownawell, 1986
-- (Stations 5, 6, 7, and 8)	Mid-1980s	7.31 - 30.9 ppm (Aroclor 1254, dry wt.)	Hansen et al., 1986
-- (Stations 2-10)	1986 (Jan. 21-22)	3.76 - 14.3 ppm (Aroclor 1254, dry wt.)	HMM Assoc., 1986

Table 5. __ Continued

Location of collection	Date of collection	Concentration of PCBs in environmental medium	Reference in scientific literature
		Surficial Sediment (cont.)	
Outer harbor SE of hurricane barrier to Clark Pt.-Willow Pt. transect (whole area)	1970s - early 1980s	< 1 - 50 ppm (Aroclor 1254, dry wt.)	Farrington et al., 1986
-- (Station 67)	1983 (Sept. 1)	33 ppm max. at sediment depth of 15-17 cm (Aroclors 1242 [21%] and 1254 [79%], dry wt.); decrease to 13 ppm at 35-41 cm	Brownawell, 1986
-- (Station 1)	1986 (Jan. 21-22)	2.64 ppm (Aroclor 1254, dry wt.)	HMM Assoc., 1986
		Interstitial Water[a]	
Inner harbor south of I-195 (Station 84)	1981 (Oct. 29)	1.57 ppb max. at sediment depth of 0 - 1 cm (Aroclors 1242 [50%] and 1254 [50%]); decrease to 0.030 ppb at 27-30 cm	Brownawell, 1986
Outer harbor SE of hurricane barrier to Clark Pt.-Willow Pt. transect (Station 67)	1983 (Sept. 1)	20.13 ppb max. at sediment depth of 9 - 11 cm (Aroclors 1242 [15%] and 1254 [85%]); decrease to 8.18 ppb at 35-41 cm	Brownawell, 1986

Table 5. __ Continued

Location of collection	Date of collection	Concentration of PCBs in environmental medium	Reference in scientific literature
		Water[b]	
Inner harbor north of I-195 ("Hot Spot")	1984 (May 18)	4.0 ppb (total PCBs); max. level	Battelle, undated
Inner harbor south of I-195 (Station 84)	1981 (Oct. 29)	0.170 ppb (Aroclors 1242 and 1254)	Brownawell, 1986
Outer harbor SE of hurricane barrier to Clark Pt.-Willow Pt. transect (Station 74)	1982 (Sept. 22)	0.011 - 0.020 ppb (Aroclors 1242 and 1254)	Brownawell, 1986
Inner and outer harbors	1970s - early 1980s	0.0067 - 0.265 ppb (total PCBs)	Farrington et al., 1983
		Particulate Matter	
Inner and outer harbors	Late 1970s - early 1980s	8.8 - 36 ppm (total PCBs, dry wt.)	Farrington et al., 1983

Table 5. __ Continued

Location of collection	Date of collection	Concentration of PCBs in environmental medium	Reference in scientific literature
		Biota [c]	
1. Mytilus edulis (blue mussel)			
• "New Bedford Harbor"	1976	110 ppm (Aroclor 1242, dry wt.)	Mass. Div., Mar. Fish., 1977
• Inner harbor south of I-195 (hurricane barrier)	1985 (summer)	~15ppm (total PCBs, dry wt.); 250-day transplants	Capuzzo et al., undated
2. Mya arenaria (soft-shell clam)			
• Inner harbor north of I-195 (Stations D, E. F)	1976 (Sept. 23)	21.0 - 53.0 ppm (Aroclor 1254, wet wt.)	Kolek and Ceurvels, 1981
-- (Station F)	1979 (August 16)	14.6 ppm (Aroclor 1254, wet wt.)	Kolek and Ceurvels, 1981
3. Mercenaria mercenaria (hard clam)			
• Inner harbor north of I-195 (Stations A and B)	1983 (June 14)	1.50 - 2.10 ppm (Aroclor 1254, wet wt.)	Mass. Div. Mar. Fish., undated
-- (Stations A, D, and E)	1984 (Sept. 1)	0.50 - 1.10 ppm (Aroclor 1254, wet wt.)	Mass. Div. Mar. Fish., undated

Table 5. __ Continued

Location of collection	Date of collection	Concentration of PCBs in environmental medium	Reference in scientific literature
		Biota (cont.)[c]	
3. M. mercenaria (cont.)			
• Inner harbor south of I-195 (Stations "D" and "E")	1978 (Oct. 12)	2.50 - 4.86 ppm (Aroclors 1242 and 1254, wet wt.); Aroclor 1242 predominated	Deubert et al.,1981
-- (Station NN)	1979 (Aug. 16)	1.6 ppm (Aroclor 1254, wet wt.)	Kolek and Ceurvels, 1981
• Outer harbor SE of hurricane barrier to Clark Pt.-Willow Pt. transect (Stations Q, KK, and JJ)	1976 (Sept. 23)	0.7 - 3.3 ppm (Aroclor 1254, wet wt.)	Kolek and Ceurvels, 1981
-- (Stations "A", "C", "F", and "G")	1978 (Oct. 12)	0.35 - 6.93 ppm (Aroclors 1242 and 1254, wet wt.); Aroclor 1242 predominated	Deubert et al., 1981
-- (Stations II, R, and JJ)	1979	0.3 - 0.8 ppm (Aroclor 1254, wet wt.)	Kolek and Ceurvels, 1981

a Interstitial water is "pore water" intimately associated with sediment.

b Concentrations of PCBs in water pertain to dissolved material.

c Biota addressed in this table are limited to comparatively immobile benthic invertebrates, for which histories of exposure to PCBs can be relatively well documented. American lobsters collected from the study area have occasionally been reported to contain PCBs at levels several times greater than the FDA action level of 2 ppm, wet wt. (Kolek and Ceurvels, 1981; Mass. Div. Mar. Fish, undated). Fishes obtained from the study area that consistently contained PCB levels greater than the FDA criterion are the American eel and windowpane flounder (Kolek and Ceurvels, 1981; Mass. Div. Mar. Fish., undated).

outer harbor. However, concentrations of PCBs in particulate matter present in the water column of New Bedford Harbor have been reported (Farrington et al., 1983) to range from 8.8 to 36 ppm.

Biota -- primarily macrobenthic invertebrates and demersal fishes -- inhabitating selected areas of New Bedford Harbor have been characterized by elevated body burdens of PCBs (Table 5). Blue mussels have been reported to contain body burdens of PCBs up to 110 ppm, dry wt. (Mass. Div. Mar. Fish., 1977); and soft-shell clams indigenous to the northern part of the inner harbor have contained PCB levels that ranged from 14.6 to 53.0 ppm, wet wt. (Kolek and Ceurvels, 1981). Hard clams (quahogs) from New Bedford Harbor have often contained body burdens of PCBs in the low ppm (wet wt.) range (Table 5). American lobsters collected from the study area occasionally contained PCBs at concentrations several times the FDA "wet wt." action level of 2 ppm (Kolek and Ceurvels, 1981; Mass. Div. Mar. Fish., undated). The only fishes that consistently were characterized by PCB levels in excess of the FDA criterion were the American eel and windowpane flounder (Kolek and Ceurvels, 1981; Mass. Div. Mar. Fish., undated).

5. ASSESSMENT OF AQUATIC HAZARD POSED BY PCBs TO MARINE ORGANISMS INHABITATING NEW BEDFORD HARBOR

Assessment of the aquatic hazard of xenobiotic constituents to aquatic organisms is classically predicated upon a two-fold approach in which: 1) concentrations of constituents demonstrated in the laboratory to toxicologically affect organisms are compared to environmental levels of constituents; and 2) results of the laboratory-based approach are empirically verified by observations in the field. The laboratory-based approach typically incorporates "worst-case" features into its experimental design (e.g., the forced exposure of organisms to unfluctuating levels of the most toxic forms of constituents) and, consequently, tends to "over-predict" the aquatic hazard observed in the field, where exposure scenarios are highly variable.

As discussed in the preceding part of this document, the xenobiotic constituents of greatest concern in New Bedford Harbor are Aroclors 1016, 1242 and 1254. These particular PCB formulations are likely to be less toxic to marine organisms than the more chlorinated formulations (e.g., Aroclor 1260) and, although probably more available for uptake by organisms than the more chlorinated and less water-soluble formulations, are less likely to be maintained in the tissues of the organisms if bioaccumulated (i.e., are more likely to be depurated by the organisms). Uptake of the formulations does not imply aquatic hazard to the organisms themselves, and body burdens of the formulations in organisms appear unlikely to be substantially biomagnified at higher levels in the ecological food chain. Aroclors 1016, 1242 and 1254 are also subject to continuous natural attenuation in New Bedford Harbor. For example, approximately 35% of the PCBs introduced into the upper Acushnet River Estuary during the late 1940s into the 1970s has been eliminated from the New Bedford Harbor area (Brown and Wagner, 1986). (Attenuation of Aroclor 1254 by natural process was also observed in Escambia Bay, Florida, where sedimentary concentrations as high as approximately 500 ppm [Duke et al., 1970] were reduced by about 90% within the period of one year [Nimmo et al., 1975].)

The laboratory-based (i.e, predictive) approach to the assessment of PCB-related toxicological hazard to organisms indigenous to New Bedford Harbor is emphasized in the remaining part of this document. However, the results of this approach, which is differentially applied in the case of water-column organisms (i.e., plankton and fishes) as contrasted to benthos, are consistent with empirical observations in New Bedford Harbor. For example, Kolek and Ceurvels (1981) reported that numerous species of finfishes (and various benthic macroinvertebrates as well) collected from New Bedford Harbor over a 4-year period (1976-1980) never exhibited abnormalities or indications of disease even though body burdens of PCBs in the organisms sometimes exceeded 500 ppm. Conversely, studies performed by the U.S. Army Corps of Engineers (COE, 1986) in the upper estuary of New Bedford Harbor (in the proximity of one of the industrial sources of PCBs) indicated altered community structure of macroinvertebrates. However, a causal relationship between PCB contamination and altered community structure cannot be positively established because of such confounding sources of variation as the physical suitability (in terms of grain-size distribution of sediment, current regimes, siltation, exposure of substrate to the atmosphere, etc.) of the upper estuary for specific species of macroinvertebrates and the presence of other xenobiotic constituents (e.g., metals) in estuarine sediment.

5.1 Plankton and Fishes (Lagrangian Assessment)

Plankton (phytoplankton and zooplankton) and fishes exhibit either passive or active horizontal mobility and hence, have, or can be assumed to have (EPA, 1977; EPA and COE, 1977; Rose and Ward, 1981; EPA 1985), predictable temporally dependent (i.e., Lagrangian) exposure patterns in which organisms characteristically experience constantly decreasing concentrations of xenobiotic constituents. Since these exposure patterns are not infinite in length, chronic water quality criteria (e.g., 0.030 ppb in the case of PCBs and marine organisms; EPA, 1986) are inappropriate for comparison to environmental concentrations of xenobiotic constituents in aquatic-hazard assessments for mobile organisms. Conversely, a comparison made on an exposure-time-dependent basis -- i.e., comparison of a time-series water quality criterion (e.g., MATC) for a constituent to the time-related environmental concentration of the constituent -- has a sound

technical foundation (e.g., EPA,1977; EPA and COE, 1977; Rose and Ward, 1981; EPA, 1985).

Phytoplankton appear to be more sensitive to PCBs than zooplankton or fishes (Table 1). Worst-case MATCs for maintenance of photosynthesis and/or cell division in phytoplankton exposed to Aroclor 1254 in water range from 3.2 ppb PCBs for a 6-hr exposure period (Harding, 1976) to < 0.1 ppb PCBs for a 144-hr (6-day) exposure period (Fisher and Wurster, 1973). The water-column above the Hot Spot in the upper Acushnet River Estuary has been characterized by PCB levels (dissolved levels) as high as 4.0 ppb (Battelle, undated). However, water-column organisms can be expected to be exposed to such elevated PCB levels for, at most, a few hours on either side of slack high tide in the vicinity of the Hot Spot (not for the 6-hr period associated with the MATC of 3.2 ppb PCBs). With even a modest current (5 cm/sec) prevailing at the Hot Spot (which occupies an approximately 335-m noncongruous stretch of the estuary [Ebasco Serv., 1989]), a parcel of water (and associated plankton) would pass through the area in about 1.9 hr and, then, would be rapidly diluted with less contaminated water to levels probably well below the 6-hr MATC of 3.2 ppb (a dilution factor of just 1.3 x applied to a water concentration of 4.0 ppb PCBs would be required to achieve the 6-hr MATC of 3.2 ppb).

In the case of fishes, MATCs for acute exposure to Aroclors 1016 or 1254 in water are > 10.0 ppb PCBs for a 24-hr exposure period (fertilization efficiency of sheepshead minnows; Table 1; Schimmel et al., 1974); > 100 ppb PCBs for a 48-hr exposure period (survival of juvenile pinfish; Duke et al., 1970); > 100 ppb PCBs for a 96-hr exposure period (survival of pinfish; Hansen et al., 1974a) ; and 5.7 ppb PCBs for a 7-day exposure period (embryo development of sheepshead minnows; Schimmel et al., 1974) . These MATC values are clearly higher than comparable aqueous levels of PCBs in New Bedford Harbor. An additional environmental safeguard for fishes may be their ability to avoid water contaminated with PCBs. Hansen et al. (1974b) demonstrated in laboratory tests that pinfish (and mosquitofish, a freshwater species) were capable of avoiding extremely high concentrations of Aroclor 1254 (levels ranging from 100 to 10,000 ppb; tests were conducted with PCBs dissolved in an acetone carrier). However, similar avoidance reactions to Aroclor 1254 were not observed by Hansen for sheepshead minnows.

The above-described Lagrangian-based assessment indicates that the presence of PCBs in New Bedford Harbor does not represent a potential for toxicological hazard to indigenous water-column organisms such as plankton and fishes.

5.2 Benthos (Eulerian Assessment)

Benthos (i.e., primarily infaunal invertebrates, as contrasted to some epifaunal invertebrates and demersal fishes) are immobile and, consequently, are characterized by spatially-dependent (i.e., Eulerian) exposure patterns that, in general, do not vary significantly as a function of short-scale time. For these organisms, which either are or are not exposed to specific concentrations of xenobiotic constituents for lengthy periods of time, a single chronic water (or sediment) quality criteria is appropriate for comparison to environmental concentrations of the constituents in aquatic-hazard assessments.

An assessment of the toxicological hazard of PCBs to benthos in New Bedford Harbor is most logically predicated upon a chronic sediment quality criterion since, in part, site-specific data supporting development of such a criterion have been generated from sediment collected from the harbor (Table 2; Hansen et al., 1986; amphipod tests). Those data suggest that an appropriate MATC for benthos may be on the order of from > 7.31 to > 66 ppm PCBs (Aroclor 1254) in sediment. It is obviously necessary to confirm these "open-ended" MATC values by additional testing, including tests in which organisms are exposed to known (i.e., spiked) amounts of PCBs in otherwise uncontaminated sediment similar in physical characteristics to sediment from New Bedford Harbor. Such testing would be capable of documenting dose-response and, hence, causal relationships between PCBs in sediment and toxicological responses of organisms. Areas of the Acushnet River Estuary in which sedimentary levels of PCBs are in excess of a reliable MATC would pose a potential toxicological hazard to benthos. Actual PCB-associated hazard to populations or stocks of benthos would be a function of such factors as the presence of other limiting factors within the areas of potential PCB-related impact and the distribution of benthos beyond the potentially impacted areas.

6. REFERENCES

Adams, J. A., 1983. Effect of PCB (Aroclor 1254) on early development and mortality in Arbacia eggs. Water, Air and Soil Pollut. 20:1-5.

Battelle. Undated. Water column PCB data associated with cruises conducted in the New Bedford Harbor area during May 1984, September-October 1984, November 1984, and June-July 1985. 33 pp.

Bengtsson, B. 1980. Long-term effects of PCB (Clophen A50) on growth, reproduction and swimming performance in the minnow, Phoxinus phoxinus. Water Res. 14:681-687.

Brinkman, U. A., Th. and A. DeKok. 1980. Production, properties and usage. In: Halogenated Biphenyls, Terphenyls, Napthalenes, Dibenxodioxins and Related Products. (ed. R.D. Kimbrough), Elsevier, NY. p. 1.

Brown, J. F., and R. E. Wagner. 1986. Polychlorinated biphenyl (PCB) movement and transformation in Acushnet Estuary sediments. Prepared by General Electric Research and Devel. Ctr., Schenectady, NY.

Brownawell, B. J. 1986. The role of colloidal organic matter in the marine geochemistry of PCBs. Ph.D. Thesis. WHOI/MIT, WHOI-86-19.

Calambokidis, J., J. Mowrer, M. W. Beug, and S. G. Herman. 1979. Selective retention of polychlorinated biphenyl components in the mussel, Mytilus edulis. Arch. Environm. Contamn. Toxicol. 8:299-308.

Capuzzo, J.M., J. W. Farrington, C. Hovey Clifford, X. Jia, B. A. Lancaster, and D. F. Leavitt. Undated. Bioaccumulation and biological effects of PCBs on marine bivalve molluscs in New Bedford Harbor, Massachusetts. 10 pp.

Carey, A. E., and G. R. Harvey. 1978. Metabolism of polychlorinated biphenyls by marine bacteria. Bull. Environm. Contamn. and Toxicol. 20 (4):527-534.

Chapman, P. M. 1989. Current approaches to developing sediment quality criteria. Environm. Toxicol. and Chem. 8:589-599.

Chapman, P. M., R. C. Barrick, J. M. Neff, and R. C. Swartz. 1987. Four independent approaches to developing sediment quality criteria yield similar values for model contaminants. Environm. Toxicol. and Chem. 6:723-725.

Chase, K. H., J. Doull, S. Friess, J. V. Rodricks, and S. H. Safe. 1989. Evaluation of the toxicology of PCBs. Prepared for Texas Eastern Gas Pipeline Co., Houston, TX. 71 pp. and 2 appendices.

Clark, J. R., J. M. Patrick, J. C. Moore, and J. Forester. 1986. Accumulation of sediment-bound PCBs by fiddler crabs. Bull. Environm. Contamn. Toxicol. 36:571-578.

Courtney, W. A., and W. J. Langston. 1978. Uptake of polychlorinated biphenyl (Aroclor 1254) from sediment and from seawater in two intertidal polychaetes. Environm. Pollut. 15:303-309.

Deubert, K. H., P. Rule, and I. Corte-Real. 1981. PCB residues in Mercenaria mercenaria from New Bedford Harbor, 1978. Bull. Environm. Contamn. Toxicol. 27:683-688.

Duke, T. W., J. I. Lowe, and A. J. Wilson, Jr. 1970. A polychlorinated biphenyl (Aroclor 1254) in the water, sediment, and biota of Escambia Bay, Florida. Bull. Environm. Contamn. Toxicol. 5(2):171-180.

Ebasco Services, Inc. 1989. Hot spot feasibility study: New Bedford Harbor (May draft). Prepared for U. S. EPA, Region I, Boston, MA.

Elder, D.L., S. W. Fowler, and G.G. Polikarpov. 1979. Remobilization of sediment-associated PCBs by the worm Nereis diversicolor. Bull. Environm. Contamn. Toxicol. 21:448-452.

Enseco. 1987. Study of water and sediment collected from New Bedford Harbor, Massachusetts. Performed for Ropes and Gray. Boston, MA.

Enseco. 1987. Study of water and sediment collected from New Bedford Harbor, Massachusetts. Performed for Ropes and Gray. Boston, MA.

ERCO. 1982. Investigations on pollutant organic chemical fluxes in the Hudson Raritan Estuarine and New York Bight coastal systems. Performed for Nat'l. Oceanographic and Atmospheric Admin., Office Mar. Pollut. Assess., Rockville, MD. 59 pp.

Farrington, J. W., A. C. Davis, B. J. Brownawell, B. W. Tripp, C. Hovey Clifford, and J. B. Livramento. 1986. The biogeochemistry of polychlorinated biphenyls in the Acushnet River Estuary, Massachusetts. In: Organic Marine Geochemistry. pp. 174-197.

Farrington, J. W., J. Sulanowski, A. C. Davis, N. Staresinic, B. W. Tripp, H. Levin, and L. Stathoplos. 1983. PCB biogeochemistry in the Acushnet River Estuary, Massachusetts. In: Program and Abstracts for the Fourth Annual Intnat'l Ocean Disposal Sympos., Plymouth Polytechnic, Plymouth, Devon, England. pp. 165-167.

Fingerman, S. W. 1980. Differences in the effects of fuel oil, an oil dispersant, and three polychlorinated biphenyls on fin regeneration in the Gulf Coast killifish, Fundulus grandis. Bull. Environm. Contamn. Toxicol. 25:234-240.

Fingerman, S. W., and M. Fingerman.. 1979. Comparison of the effects of fourteen-day and chronic exposures to a polychlorinated biphenyl, Aroclor 1242, on molting of the fiddler crab, Uca pugilator. Bull. Environm. Contamn. Toxicol. 21(3):352-357.

Fisher, N. 1975. Chlorinated hydrocarbon pollutants and photosynthesis of marine phytoplankton: a reassessment. Science 189:463-464.

Fisher, N. S., and C. F. Wurster. 1973. Individual and combined effects of temperature and polychlorinated biphenyls on the growth of three species of phytoplankton. Environm. Pollut. 5:205-212.

Fowler, S. W., G. G. Polikarpov, D. L. Elder, P. Parsi, and J.-P. Villeneuve. 1978. Polychlorinated biphenyls: accumulation from contaminated sediments and water by the polychaete Nereis diversicolor. Mar Biol. 48:303-309.

Fresenius, W., I. Luederwald, and J. M. Neff. 1984. Bioaccumulation of organic micropollutants from sediments and suspended particulates by aquatic animals. Intn'l Wkshp Transport Organic Micropollut. Hydrological Cycle pp.132-136.

Goerke, H., G. Eder, K. Weber, and W. Ernst. 1979. Patterns of organochlorine residues in animals of different trophic levels from the Weser estuary. Mar. Pollut. Bull. 10(5):127-133.

Hansen, D. J., P. R. Parrish, and J. Forester. 1974a. Aroclor 1016: toxicity to and uptake by estuarine animals. Environm. Res. 7:363-373.

Hansen, D. J., P. R. Parrish, J. I. Lowe, A. J. Wilson, Jr. and P. D. Wilson. 1971. Chronic toxicity, uptake, and retention of Aroclor 1254 in two estuarine fishes. Bull. Environm. Contamn. Toxicol. 6(2):113-119.

Hansen, D. J., P. Rogerson, K. J. Scott, M. Redmond, W. Berry, R. Pruell, and W. Boothman. 1986. Preliminary data report: New Bedford Harbor project. U. S. EPA (Narragansett Laboratory) and Science Applications International Corp. 25 pp.

Hansen, D.J ., S. C. Schimmel, and J. Forester. 1975. Effects of Aroclor 1016 on embryos, fry, juveniles, and adults of sheepshead minnows (Cyprinodon variegatus). Trans. Amer. Fish. Soc. 104 (3): 584-588.

Hansen, D. J., S .C. Schimmel, and E. Matthews. 1974b. Avoidance of Aroclor 1254 by shrimp and fishes. Bull. Environm. Contamn.Toxicol. 12(2):253-256.

Harding, Jr., L. W. 1976. Polychlorinated biphenyl inhibition of marine phytoplankton photosynthesis in the Northern Adriatic Sea. Bull. Environm. Contamn. Toxicol. 16(5):559-566.

Harding, Jr., L. W., and J. H. Phillips, Jr. 1978a. Polychlorinated biphenyl (PCB) effects on marine phytoplankton photosynthesis and cell division. Mar. Biol. 49:93-101.

Harding, Jr., L. W., and J. H. Phillips, Jr. 1978b. Polychlorinated biphenyl (PCB) uptake by marine phytoplankton. Mar. Bio. 49: 103-111.

HMM Associates. 1986. *Cruise report: New Bedford Harbor sediment sampling;* January 21-22, 1986. HMM draft document No. 85-944-15(2). Prepared for Dept. of the Army, N.E. Div., Corps of Engin., Waltham, MA. 54 pp.

Hutzinger, O., S. Safe, and V. Zitko. 1974. The chemistry of PCBs. CRC Press, Cleveland, OH. p. 1.

Iseki, K., M. Takahashi, E. Bauerfeind, and C. S. Wong. 1981. Effects of polychlorinated biphenyls (PCBs) on a marine plankton population and sedimentation in controlled ecosystem enclosures. Mar. Ecol. 5:207-214.

Kimbrough, R. D. 1980. Environmental pollution of air, water and soil. In: Halogenated Biphenyls, Terphenyls, Naphthalenes, Dibenzodioxins and Related Products. Elsevier/North Holland Biomedical Press. p. 77.

Kolek, A., and R. Ceurvels. 1981. Polychlorinated biphenyl (PCB) analyses of marine organisms in the New Bedford area: 1976-1980. Comm. of Mass., Div. Marine Fisheries. 27 pp. and 2 appendices.

Langston, W. J. 1978a. Accumulation of polychlorinated biphenyls in the cockle Cerastoderma edule and the tellin Macoma balthica. Mar. Biol. 45:265-272.

Langston, W.J. 1978b. Persistence of polychlorinated biphenyls in marine bivalves. Mar. Biol. 46:35-40.

Lowe, J. I., P. R. Parrish, J. M. Patrick, Jr., and J. Forester. 1972. Effects of the polychlorinated biphenyl Aroclor 1254 on the American oyster Crassostrea virginica. Mar. Biol. 17:209-214.

Macek, K. J., S. R. Petrocelli, and B. H. Sleight, III. 1979. Considerations in assessing the potential for and significance of biomagnification of chemical residues in aquatic food chains. In: Amer. Soc. Test. Mater. STP 667. pp. 251-268.

Massachusetts Division of Marine Fisheries. 1977. Data sheets containing PCB residues of sediments and various bivalves. E. Sandwich, MA.

Massachusetts Division of Marine Fisheries. Undated. PCBs in New Bedford Harbor: 6/1/77-2/4/86. Cat Cove Laboratory, Salem, MA. 8 pp.

Mayer, F. J., Jr. 1986. Acute toxicity handbook of chemicals to estuarine animals. EPA/600/86/231. 274 pp.

Mayer, F. L., P. M. Mehrle, and H. O. Sanders. 1977. Residue dynamics and biological effects of polychlorinated biphenyls in aquatic organisms. Arch. Environm. Contamn. Toxicol. 5:501-511.

McLeese,D. W., C. D. Metcalfe, and D. S. Pezzack. 1980. Uptake of PCBs from sediment by Nereis virens and Crangon septemspinosa. Arch. Environm. Contamn. Toxicol. 9:507-518.

Mosser, J. L., T. Teng, W. G. Walther, and C. F. Wurster. 1974. Interactions of PCBs, DDT and DDE in a marine diatom. Bull. Environm. Contamn. Toxicol. 12(6):665-668.

National Oceanic and Atmospheric Administration. 1979. The New York Bight. In: Proceedings of Workshop on Assimilative Capacity of U.S. Coastal Waters for Pollutants. Crystal Mountain, WA. pp. 148-178.

Nimmo, D. R., R. R. Blackman, A. J. Wilson, Jr., and J. Forester. 1971a. Toxicity and distribution of Aroclor 1254 in the pink shrimp Penaeus duorarum. Mar. Biol. 11:191-197.

Nimmo, D. R., D. J. Hansen, J. A. Couch, N. R. Cooley, P .R. Parrish, and J. I. Lowe. 1975. Toxicity of Aroclor 1254 and its physiological activity in several estuarine organisms. Arch. Environm. Contamn. Toxicol. 3(1):22-39.

Nimmo, D. R., P. D. Wilson, R. R. Blackman, and A. J. Wilson, Jr. 1971b. Polychlorinated biphenyl absorbed from sediments by fiddler crabs and pink shrimp. Nature 231:50-52.

O'Connor, J. M., and J. C. Pizza. 1983. A blend of kinetics and physiology describes bioaccumulation of contaminants in marine fishes. In: Program and Abstracts for the Fourth Annual Intnat'l Ocean Disposal Sympos. Plymouth Polytechnic, Plymouth, Devon, England. pp. 94-95.

Office of Technology Assessment. 1987. Wastes in marine environments. OTA-O-334, U. S. Government Printing Office,Washington, D.C. 313 pp.

Osterberg, C., and S. Keckes. 1977. The state of pollution of the Mediterranean Sea. Ambio: A Journal of Human Environ., Res., Mgmt. 6(6):321-326.

Parrish, P. R., D. J. Hansen, J. A. Couch, J. M. Patrick, Jr., and G. H. Cook. 1974. Effects of the polychlorinated biphenyl, Aroclor 1016, on estuarine animals. Abst. ASB Bull. 21(2): 74.

Pavlou, S.P. 1987. The use of the equilibrium partitioning approach in determining safe levels of contaminants in marine sediments. In: Fate and Effects of Sediment Bound Chemicals in Aquatic Systems. K. L. Dickson, et al., editors. Pergamon Press. pp. 388-412.

Plesha, P. D., J. E. Stein, M. H. Schiewe, B. B. MCCain, and U. Varanasi. 1988. Toxicity of marine sediments supplemented with mixtures of selected chlorinated and aromatic hydrocarbons to the infaunal amphipod Rhepoxynius abronius . Mar. Environm. Res. 25:85-97.

Pruell, R. J., J. L. Lake, W. R. Davis, and J. G. Quinn. 1986. Uptake and depuration of organic contaminants by blue mussels (Mytilus edulis) exposed to environmentally contaminated sediment. Mar. Biol. 91:497-507.

Risebrough, R. W., B. W. DeLappe, T. T. Schmidt. 1976. Bioaccumulation factors of chlorinated hydrocarbons between mussels and seawater. Mar. Pollut. Bull. 7(12):225-228.

Roesijadi, G., J. W. Anderson, and C. S. Giam. 1976c. Osmoregulation of the grass shrimp Palaemonetes pugio exposed to polychlorinated biphenyls (PCBs). II. Effect on free amino acids of muscle tissue. Mar. Biol. 38:357-363.

Roesijadi, G., J. W. Anderson, S. R. Petrocelli, and C. S. Giam. 1976b. Osmoregulation of the grass shrimp Palaemonetes pugio exposed to polychlorinated biphenyls (PCB)s. I. Effect on chloride and osmotic concentrations and chloride- and water-exchange kinetics. Mar. Biol. 38:343-356.

Roesijadi, G., S. R. Petrocelli, J. W. Anderson, C. S. Giam, and J. E. Neff. 1976a. Toxicity of polychlorinated biphenyls (Aroclor 1254) to adult, juvenile and larval stages of the shrimp Palaemonetes pugio. Bull. Environm. Contamn. Toxicol. 15:297-304.

Rose, C. D., and T. J. Ward. 1981. Principles of aquatic hazard evaluation as applied to ocean-disposed wastes. In: Amer. Soc. Test. Mater. STP 737. pp. 138-158.

Rubinstein, N. I., E. Lores, and N. R. Gregory. 1983. Accumulation of PCBs, mercury and cadmium by Nereis virens, Mercenaria mercenaria and Palaemonetes pugio from contaminated harbor sediments. Aquatic Toxicol. 3:249-260.

Safe, S. 1984. Polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PBBs): biochemistry, toxicology, and mechanism of action. CRC Critical Reviews Toxicol. 13(4):3193-395.

Sayler, G.S., R. Thomas, and R.R. Colwell. 1978. Polychlorinated biphenyl (PCB) degrading bacteria and PCB in estuarine and marine environments. Estuar. and Mar. Sci. 6(6):553-567.

Schimmel, S. C., D. J. Hansen, and J. Forester. 1974. Effects of Aroclor 1254 on laboratory-reared embryos and fry of sheepshead minnows (Cyprinodon variegatus). Trans. Amer. Fish Soc. 103 (3)3:582-586.

Scura, E. D., and G. H. Theilacker. 1977. Transfer of the chlorinated hydrocarbon PCB in a laboratory marine food chain. Mar. Biol. 40:317-325.

Shaw, G. R., and D. W. Connell. 1980. Polychlorinated biphenyls in the Brisbane River Estuary, Australia. Mar. Pollut. Bull. 11(12):356-358.

Stein, J. E., T. Hom, E. Casillas, A. Friedman, and U. Varanasi. 1987. Simulataneous exposure of english sole (Parophrys vetulus) to sediment-associated xenobiotics: Part 2 - chronic exposure to an urban estuarine sediment with added ^{3}H-benzo [a] pyrene and ^{14}C-polychlorinated biphenyls. Mar. Environm. Res. 22:123-149.

Tanabe, S., H. Tanaka, and R. Tatsukawa. 1984. Polychlorobiphenyls, Sigma DDT, and hexachlorocyclohexane isomers in the western North Pacific ecosystem. Arch. Environm. Contamn. Toxicol. 13(6):731-773.

Teeter, A .M. 1988. New Bedford Harbor Superfund Project, Acushnet River Estuary engineering feasibility study of dredging and dredged material alternatives; Report 2, sediment and contaminant hydraulic transport investigations; Technical Report EL-88-15; U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thomann, R. V. 1981. Equilibrium model of fate of microcontaminants in diverse aquatic food chains. Can. J. Fish. Aqua. Sci. 38:280-296.

Tjeerdema, R. S., and R. S. Jacobs. 1987. Elimination of 2,4,5,2',4',5'-hexachlorobiphenyl by the purple sea urchin, Strongylocentrotus purpuratus, following single exposure. Bull. Environm. Contamn. Toxicol. 38:1029-1036.

U.S. Army Corps of Engineers, New England Division, 1986. Macrobenthic survey for New Bedford Harbor.

U.S. Environmental Protection Agency. 1977 (and later revisions). Ocean dumping: final revision of regulations and criteria. Fed. Reg. 42(7):2462-2490.

U.S. Environmental Protection Agency. 1985. Technical support document for water quality-based toxics control. EPA - 440/4-85-032. U. S. EPA, Washington, DC. 75 pp and 5 appendices.

U.S. Environmental Protection Agency. 1986. Quality criteria for water. EPA 440/5-86-001. U. S. EPA, Washington, DC. 397 pp.

U.S. Environmental Protection Agency and U. S. Army Corps of Engineers. 1977. Ecological evaluation of proposed discharge of dredged material into ocean waters. Implementation Manual for Section 103 of Public Law 93-532 (Marine Protection, Research, and Sanctuaries Act of 1972). Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 24 pp. and 8 appendices.

van den Broek, W.L.F. 1979. Seasonal levels of chlorinated hydrocarbons and heavy metals in fish and brown shrimps from the Medway estuary, Kent. Environm. Pollut. 19(1):21-38.

Vreeland, V. 1974. Uptake of chlorobiphenyls by oysters. Environm. Pollut. 6:135-140.

Wildish, D.J. 1970. The toxicity of polychlorinated biphenyls (PCB) in sea water to Grammarus oceanicus. Bull. Environm. Contamn. Toxicol. 5(3):202-204.

APPENDIX A

RESUME OF AUTHOR OF DOCUMENT

CURT D. ROSE

EDUCATION

Ph.D., Aquatic Ecology, North Carolina State University at Raleigh, 1966.
B.A., Zoology, University of Maine at Orono, 1960.

EXPERIENCE

Dr. Rose is an aquatic ecologist with experience in marine, estuarine, and freshwater systems. His major area of expertise is the evaluation of biological hazard associated with the discharge of wastes to aquatic environments. He has conducted such evaluations in Canada, Europe, the Republic of Korea, and the Republic of China (Taiwan), as well as in the United States, for a variety of wastes -- including drilling fluids, produced waters, dredged materials, sewage sludge, coal ash, and acid-iron wastes. Dr. Rose is also an applied statistician, and has authored sampling procedures for EPA's Office of Solid Wastes (Test Methods for Evaluating Solid Waste, second edition). Dr. Rose has taught general and advanced courses in biology at several universities in Louisiana and Maryland.

EMPLOYMENT

CDR Environmental Specialists, Incorporated (1988-present): President and Chief Scientist. Representative scientific projects are:

"Bioassessment of a Superfund Site -- the Maryland Sand, Gravel, and Stone Site" (For Clean Sites, Inc.). Program Director and Chief Scientist. Comprehensive field and laboratory bioassessment in Region III, EPA, that included wetland identification and delineation, benthos and fish survey, chemical analyses, and aquatic-toxicity tests. Study performed in 1988 - 1989.

"Evaluation of Environmental Effects Associated with Discharge of Industrial Waste at the New York Bight Acid Waste Disposal Site as Compared to Effects of Feasible Land-Based Alternatives" (For Allied-Signal, Inc.). Program Director and Chief Scientist. Literature, field, and laboratory study in support of application for an ocean dumping permit in Region II, EPA. Study performed in 1988 - 1989.

"Mathematical Modeling and Dye Verification Study for Industrial Effluent Discharged to Newark Bay" (For Allied-Signal, Inc.). Program Director and Chief Scientist. Modeling and dye verification study in response to NPDES permit conditions established by State of New Jersey. Study performed in 1988.

"NPDES Biomonitoring Program for Sewage Sludge Discharged from MWRA's Treatment Plants at Deer Island and Nut Island to Boston Harbor" (For Enseco, Inc.). Technical Consultant. Evaluation of sewage effluents for chemical characteristics and aquatic toxicity. Also, assessment of potential of chemical constituents of effluents to bioaccumulate (trayed mussel study). Investigation performed in 1987-1988.

"Physical, Chemical, and Biological Oceanographic Monitoring Program at the Acid Waste Disposal Site in New York Bight" (For Enseco, Inc.). Program Director and Chief Scientist. Continuation of ten-year field program (1979-1988) to evaluate fate and effects of acid waste disposal.

Enseco, Inc. (1977-1988): Senior Scientific Specialist, Enseco. Previous positions at Enseco included: President, ERCO Division of Enseco (1980-1984); Senior Corporate Vice President, Enseco (1985-1987); Member, Board of Directors, Enseco (1984-1986); Member, Board of Directors, Enseco Investments (1984-1988). Representative scientific projects are:

"NPDES Biomonitoring Program for Sewage Sludge Discharged from MWRA's Treatment Plants at Deer Island and Nut Island to Boston Harbor" (For Massachusetts Water Resources Authority). Program Director and Chief Scientist. Assessment of sewage effluents for chemical characteristics and aquatic toxicity. Also, evaluation of potential chemical constituents of effluents to bioaccumulate (trayed mussel study). Investigation performed in 1987-1988.

"Environmental Assessment of Fly-Ash Disposal off the Coast of Taiwan, Republic of China" (For Taiwan Power Company). Program Manager and Chief Scientist. Comprehensive aquatic hazard evaluation that included both laboratory investigations (e.g., chemical analyses, aquatic-toxicity analyses, environmental fate studies employing physical models) and field investigations (e.g., plume studies, side-scan-sonar studies, underwater-television studies). Study performed in 1987-1988.

"Environmental Assessment of Various Alternatives for Disposing of Acid-Iron Waste in the Sea of Japan" (For E.I. Du Pont De Nemours & Company). Program Manager and Chief Scientist. Literature and field evaluation of two alternatives: discharge of unaltered liquid waste off the coast of the Republic of Korea and solidification of waste into monoliths to be employed in construction of artificial fishing reefs. Study performed in 1987-1988.

"Preparation of Ocean-Dumping Permit (Subparts B, C, D, and E Demonstrations) for By-product Hydrochloric Acid Discharged at Acid Waste Disposal Site in New York Bight" (For Allied-Signal). Program Manager and Chief Scientist. Literature- and laboratory-based ecological/economic evaluation presented to Region II, EPA. Studies performed in 1976, 1979, 1982, 1985, and 1988.

"Physical,, Chemical, and Biological Monitoring Program at the Acid Waste Disposal Site in New York Bight" (For Allied-Signal). Program Manager and Chief Scientist. Ten-year field program (1979-1988) to evaluate fate and effects of acid-waste disposal.

"Physical, Chemical, and Biological Monitoring Program at Deepwater Dumpsite 106" (For E.I. Du Pont De Nemours & Company). Program Manager and Chief Scientist. Five-year field program (1984-1988) to evaluate fate and effects of acid-iron waste disposal.

"Ecological Evaluation of Proposed Oceanic Discharge of Dredged Material from Numerous Locations in New England" (For New England Division, Corps of Engineers). Program Manager and Chief Scientist. Laboratory-based aquatic-toxicity and bioaccumulation analyses. Study performed in 1982-1988.

"Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico - Fish and Crustacean Bioassays" (For National Marine Fisheries Service). Program Manager and Chief Scientist. Laboratory- and field-based aquatic toxicity investigation. Study performed in 1977.

"Evaluation of Environmental Suitability of Two Potential Disposal Sites off the Coast of Taiwan to Receive Acid-Iron Waste" (For E.I. Du Pont De Nemours & Company). Program Manager and Chief Scientist. Literature study designed to facilitate selection of appropriate disposal site by the Taiwan Environmental Protection Agency. Study performed in 1987.

"Preparation of Ocean-Dumping Permit (Subparts B, C, D, and E Demonstrations) for Sewage Sludge Discharged at Deepwater Dumpsite 106" (For Massachusetts Water Resource Authority). Program Manager and Chief Scientist. Literature- and laboratory-based ecological/economic evaluation presented to Regions I and II, EPA. Study performed in 1985.

"Processing of Drilling Fluids for Environmental Testing" (For American Petroleum Institute). Program Manager and Chief Scientist. Laboratory-based evaluation of toxicological, chemical, and microbiological deterioration of drilling fluids under various storage conditions. Study performed in 1985.

"Testing of Drilling Fluids for Acute Toxicity" (For American Petroleum Institute). Program Manager and Chief Scientist. Development and validation of 17 critical testing protocols and interpretive techniques employed in evaluating drilling fluids for acute toxicity. Study performed in 1985.

"Aquatic Hazard Associated with Disposal of Acid-Iron Waste in the North Sea" (For Kronos Titan-GmbH). Program Manager and Chief Scientist. Results presented in form of expert testimony at The Hague, Netherlands. Study performed in 1982.

"Interpretation of the 1977 Ocean Dumping Regulations and Associated EPA/COE Guidelines" (For New England Division, Corps of Engineers). Program Manager and Chief Scientist. Interpretation of statistical procedures employed in ecological evaluations of dredged material. Study performed in 1982.

"Preparation of Ocean-Dumping Permit (Subparts B, C, D, and E Demonstrations) for Coal Ash Discharged at Deepwater Dumpsite 106" (For Con Edison of New York). Program Manager and Chief Scientist. Literature- and laboratory- and field-based ecological/economic evaluation presented to Region II, EPA. Study performed in 1981.

"Aquatic Hazard Evaluations for Acid-Iron Wastewaters Discharged from Two Titanium-Dioxide Manufacturing Plants to the St. Lawrence River, Quebec Province, Canada" (For Canadian Titanium Pigments, Ltd. and Tioxide Canada, Inc.). Program Manager and Chief Scientist. Chemical analyses of wastewater plumes, aquatic toxicity testing of wastewaters with freshwater animals, and field bioaccumulation studies. Study performed in 1980.

"Aquatic Hazard Evaluations for Ammonia-Containing Wastewater Discharged to the Missouri River from a Plant in La Platte, Nebraska" (For Allied-Signal). Project Manager and Chief Scientist. Field and modeling studies of wastewater plume. Study performed in 1979.

"Preparation of Ocean-Dumping Permit (Subparts B, C, D, and E Demonstrations) for Acid-Iron Waste Discharged at Acid Waste Disposal Site in New York Bight" (For NL Industries). Program Manager and Chief Scientist. Literature- and laboratory-based ecological/economic evaluation presented to Region II, EPA. Study performed in 1978.

"Technical and Environmental Assessment of Coal Cleaning -- Health and Ecological Effects Tests" (For Versar Corporation). Program Manager and Chief Scientist. Laboratory-based evaluation of toxicity of chemical substances to aquatic organisms and mammals. Study performed in 1978.

"Preparation of Ocean Dumping Permit (Subparts B, C, D, and E Demonstrations) for Acid-Iron Waste Discharged at Acid Waste Disposal Site in New York Bight" (For Gulf & Western). Program Manager and Chief Scientist. Literature- and laboratory-based ecological/economic evaluation presented to Region II, EPA. Study performed in 1977.

EG&G Environmental Consultants (1974-1977): Director of Biological Sciences Group

University of Maryland, Chesapeake Biological Laboratory (1971-1974): Research Associate Professor

Nicholls State University (1966-1971): Associate Professor of Marine Sciences

Southeastern Louisiana State University (1963-1966): Assistant Professor of Biology

EXPERT TESTIMONY

Aquatic hazard associated with disposal of fly ash off the coast of Taiwan and criteria for selection of optimal disposal sites (For Taiwan Power Company). Meeting attended by representatives of Taiwan Environmental Protection Agency. Taipei, Taiwan (Republic of China). 1987.

Ecological effects associated with ocean dumping of acid-iron wastes and environmentally appropriate disposal sites offshore of Taiwan (For E.I. Du Pont De Nemours & Company). Meeting attended by representatives of Taiwan's academic community. Taipei, Taiwan (Republic of China). 1987.

Environmental impacts of discharged acid-iron wastes and environmentally suitable disposal sites offshore of the Republic of Korea in the Sea of Japan (For E.I. Du Pont De Nemours & Company). Meeting attended by representatives of Korea's academic community and environmental agencies. Edge Moor, Delaware. 1987.

Acute toxicity and aquatic hazard related to discharge of produced waters in Santa Barbara Channel, California (For California Offshore Operators' Ad Hoc Committee). EPA, Region IX, workshop. Santa Barbara, California. 1984.

Potential ecological effects associated with runoff of herbicides to two Massachusetts streams (For American Railroad Association). Hearing before Massachusetts Department of Environmental Quality Engineering. Boston and Worcester, Massachusetts. 1984.

Relative environmental impacts of disposing of ferric chloride waste by ocean-based versus land-based alternatives (For E.I. Du Pont De Nemours & Company). EPA, Region III, hearing. Dover, Delaware. 1984.

Acute toxicity and aquatic hazard related to discharge of produced waters to offshore southern California waters (For California Offshore Operators' Ad Hoc Committee). EPA, Region IX hearing. Santa Barbara, California. 1983.

Aquatic hazard associated with disposal of acid-iron waste in the North Sea (For Kronos Titan-GmbH). The Hague, Netherlands. 1982.

Review of environmentally related testimony of Greenpeace (For NL Industries). EPA, Region II, hearing. New York, New York. 1982.

Acute toxicity and hazard associated with materials discharged from petroleum platforms located off the southern California coast (For Offshore Operations' Ad Hoc Committee). EPA Region IX, hearing. Santa Barbara, California. 1981.

Aquatic hazard evaluations of wastes proposed for discharge during exploratory drilling in the vicinity of the Flower Garden Banks (For Offshore Operators' Ad Hoc Committee). EPA Region VI, hearing. New Orleans, Louisiana.

Ocean dumping of wastes. EPA, Region II, hearing. New York, New York. 1978.

Aquatic hazard evaluations. EPA, Region III, hearing. Philadelphia, Pennsylvania. 1977.

Aquatic hazard evaluations. Virginia Water Control Board and Department of Health. Richmond, Virginia. 1977.

Aquatic hazard evaluations. Virginia Water Control Board and Department of Health. Richmond, Virginia. 1976.

Ocean dumping of wastes. EPA, Region II, hearing. New York, New York. 1976.

Aquatic ecology. LaFourche District Court, Thibodaux, Louisiana. 1972.

Aquatic ecology. Terrebonne District Court, Houma, Louisiana. 1971.

PROFESSIONAL AFFILIATIONS AND ACTIVITIES

American Association for the Advancement of Science

Member, Panel on "Ocean Pollution Research Development and Monitoring -- North and Mid-Atlantic Regions, " NOAA, Durham, New Hampshire. 1980.

Member, Panel on "Sources" Workshop on the Carrying Capacity of U.S. Coastal Waters. NOAA, Crystal Mountain, Washington. 1979.

Member, Board of Directors, World Mariculture Society. 1971-1972.

Chairman of the Program Committee, Second Annual Meeting of the World Mariculture Society. Galveston, Texas. 1971.

Moderator of Pond Management Workshop at First Annual Meeting of the World Mariculture Society. Baton Rouge, Louisiana. 1970.

PUBLICATIONS, PRESENTATIONS, AND REPORTS (Not including reports pertaining to previously identified representative scientific projects)

Ward, T., Rose, C., and Boeri, R. "Influence of Ferric-hydroxide Floc on the Acute Toxicity of Acid-Iron Waste to Marine Organisms." Presented at meeting of Society for Environmental Toxicology and Chemistry. 1985.

Rose, C.D., Ward, T.J., and DePass, V. "Ecological Assessment for Coal Ash Dumped at Deepwater Dumpsite 106." Chapter 16: Wastes in the Ocean (1985): 389-422. (Duedall, I.W., Kester, D.R., and Park, P.K., eds.). John Wiley & Sons, Inc.

Rose, C.D. "Meaningful Measures of Marine Pollution Effects -- An Overview." Presented at the Pensacola Beach Workshop (NOAA-sponsored). April 26-29, 1982.

Rose, C.D., and Ward, T.J. 1980. "Acute Toxicity and Aquatic Hazard Associated with Discharged Formation Water." Presented at Expochem '80, October 6-9, 1980, Houston, Texas (published in Environmental Effects of Offshore Oil Production; New York: Plenum, 1981.)

Rose, C.D., and Ward, T.J. "Principles of Aquatic Hazard Evaluation as Applied to Ocean-Disposed Wastes." Presented at the American Society for Testing and Materials (ASTM) Symposium on Aquatic Toxicology, Chicago, Illinois, 1979 (published in 1981 as ASTM STP 737: 138-158).

Rose, C.D. , and Heath, E. "Viability of American Oyster, Crassostrea virginica, Spermatozoa Exposed to Stress." Ches. Sci. 1(4) (1978): 245-251.

Rose, C.D., Williams, W.G., Hollister, T., and Parrish, P. "Method for Determining Acute Toxicity of an Acid Waste and Limiting Permissible Concentration at Boundaries of an Oceanic Mixing Zone." Env. Sci. Tech. 11(4) (1977): 367-371.

Rose, C.D. "Aquatic Hazard Evaluations for Oximes Wastewater Associated with the Specialty Oximes Plant in Hopewell, Virginia." For Allied Chemical Corporation. 1977.

Rose, C.D. "Documentation of Current Methods of Assessing Impacts of Power Plants on Populations of Fishes and Shellfishes." For National Power Plant Team, U.S. Fish and Wildlife Service. 1977.

Rose, C.D., and Menzie, C. "316-a Demonstration for Brunner Island Steam Electric Plant -- Unit Nos. 1-3." For Pennsylvania Power and Light Company. 1977.

Rose, C.D. "Compliance with Ocean Dumping Final Regulations and Critieria of Proposed Discharges from Exploratory Drilling Rigs on the Mid-Atlantic Outer Continental Shelf." For Shell Oil Company and a consortium of other petroleum companies. 1977.

Mainville, C.R., and Rose, C.D. "Some Environmental Effects of an Oil Spill in the Schuylkill River." Presented at the American Society of Limnology and Oceanography, Halifax, Nova Scotia. 1975.

Rose, C.D. and Harris, A. "Extensive Culture of Penaeid Shrimp in Louisiana Salt-Marsh Impoundments." Trans. Amer. Fish. Soc. 104(2) (1975): 296-307.

Rose, C.D. "Evaluation of Environmental Impacts and Relative Costs of Current Practice and Alternatives of Disposing of By-Product Hydrochloric Acid Produced at Elizabeth, New Jersey, Works of Allied Chemical Corporation." For Allied Chemical Corporation, 1975.

Rose, C.D. "Petroleum in the Estuary." Special Report No. 5, Natural Resources Institute, Center for Environmental and Estuarine Studies, University of Maryland. 1974.

Rose, C.D., and Hassler, W.W. "Food Habits and Sex Ratios of Dolphin, Coryphaena hippurus, in the Western Atlantic Ocean off Hatteras, North Carolina." Trans. Amer. Fish Soc. 103 (1) (1974): 94-100.

Rose, C.D. "Evaluation of Potential Sites for Maryland's Production Shellfish Hatchery." For the State of Maryland. 1974.

Rose, C.D. "Effect of Dredging on Survival of the American Oyster (Crassostrea virginica) in a Coastal Bayou." Ches. Sci. 14(2) (1973): 135-138.

Rose, C.D. "Oyster Hatchery to be Built on Choptank River." Comm. Fish. News 6(4) (1973): 3.

Rose, C.D. "Salinity at Solomons and Horn Point, Maryland, with Emphasis on Salinity Patterns Considered Important to Successful Operations of Production and Research Shellfish Hatcheries." For the University of Maryland. 1973.

Rose, C.D. "Bacteria Counts (Including Coliform and Fecal Coliform) Taken at Pier and Shellfish Hatchery of Chesapeake Biological Laboratory and at Horn Point during 31 July - 5 September 1973." For the University of Maryland. 1973.

Rose, C.D. "The Basis of Effective Expert Testimony." Journal of the Louisiana Bar Association 20(1) (1972): 17-20.

Rose, C.D. "Extensive Culture of Penaeid Shrimp in Salt-Marsh Impoundments." Presented at the Atlantic Estuarine Research Society. April 1972.

Rose, C.D. "Shrimp Aquaculture in Louisiana Salt-Marsh Impoundments." Presented at the 100th Annual Meeting of American Fisheries Society, New York, New York. 1970.

Rose, C.D. "Shrimp Farming in Louisiana." Presented at the Organizational Meeting of the World Mariculture Society. Grand Terre Island, Louisiana. 1970.

Harris, A.H., and Rose, C.D. "Penaeid Shrimp Production in a Managed, Unfed, Natural Pond in South Louisiana." Asso. Southeastern Bio. Bull. 17(2) (1970): 46.

Rose, C.D., and Hassler, W.W. "Application of Survey Techniques to the Dolphin, Coryphaena hippurus, Fishery of North Carolina." Trans. Amer. Fish. Soc. 98(1) (1969): 94-103.

Rose, C.D., and Harris, A. "Pugheadedness in the Spotted Sea Trout, Cynoscion nebulosus." Quart. J. Flor. Acad. Sci. 31(4) (1968): 268-270.

Harris, A.H., and Rose, C.D. "Shrimp Predation by the Sea Catfish, Galeichthys felis." Trans. Amer. Fish. Soc. 97(4) (1968): 503-504.

Rose, C.D., and Hassler, W.W. "Age and Growth of the Dolphin, Coryphaena hippurus (Linnaeus) in North Carolina Waters." Trans. Amer. Fish. Soc. 97(3) (1968): 271-276.

Rose, C.D., and Hassler, W.W. "Occurrence of the Pompano Dolphin, Coryphaena equiselis (Linnaeus) in North Carolina Waters." Journal of the Elisha Mitchell Scientific Society 84(2) (1968).